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Technical Report 1497
April 1992

**Reconnaissance
Sampling of Storm Water
Runoff Pollution at an
Arid Industrial Navy Base**

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ADMINISTRATIVE INFORMATION

This report documents a storm water runoff sampling strategy developed for an industrial Navy base. The work was performed by the Marine Environment Branch, Code 522.

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EXECUTIVE SUMMARY

OBJECTIVE

This report documents efforts to adapt and develop monitoring methods for storm water runoff. In particular, practical difficulties in field sampling and data interpretation for ecological risk assessment are addressed.

RESULTS

The first flush of runoff at the beginning of a storm is more contaminated and toxic than runoff from much later in the storm. Contaminant levels in first-flush runoff from this industrial facility were sufficiently high to justify the implementation of management measures. The data collected in this project preceded any regulatory requirements for monitoring. This affords the Navy the opportunity to continue to take a proactive stance to recognize opportunities to implement management programs particularly suited to their facility design and operational requirements.

RECOMMENDATIONS

Management at an existing facility such as Naval Station, San Diego will involve a multifaceted approach. Best management practices can immediately influence loading rates. The facility lay-out and topography preclude application of a centralized treatment system but a distributed treatment system is feasible and is probably a cost-effective approach.

First-flush runoff is more contaminated and toxic than much later in a storm. The greatest reductions in total loadings and acute toxicity will be achieved if management measures target the first flush. Once the first flush is retained or treated, additional monitoring will identify if the remaining contaminant flux poses significant ecological risk to warrant additional management expenses.

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CONTENTS

INTRODUCTION	1
UNIQUE ASPECTS OF STORM WATER RUNOFF	1
PRACTICAL SAMPLING CONSIDERATIONS	1
SITE DESCRIPTION	2
GENERAL METHODS	4
SPECIFIC SURVEYS	8
FIRST SURVEY: 16 Jan 1990	8
Objective	8
Methods	8
Results	9
SECOND SURVEY: 31 Jan 1990	16
Objective	16
Methods	16
Results	16
THIRD SURVEY: 19 Nov 1990	17
Objective	17
Methods	17
Results	18
FOURTH SURVEY: 9 Jan 1991	23
Objective	23
Methods	23
Results	24
FIFTH SURVEY: 23-24 Oct 1991	25
Objective	25
Methods	25
Results	27
DISCUSSION	30
VARIABILITY	30
MAGNITUDE	32
Relative to NURP	32
Relative to Water-Quality Objectives	32
NUTRIENTS	33
PARTICULATE BINDING	33
FROM WATER-QUALITY OBJECTIVES TO DISCHARGE REGULATIONS	35
TOXICITY	36
Exposure Assessment	36
MANAGEMENT ALTERNATIVES	37

CONTENTS (Continued)

CONCLUSIONS	39
REFERENCES	40
APPENDICES	
A: CALCULATION OF RUNOFF COEFFICIENTS	A-1
B: LOCATION AND DRAINAGE BASIN DESCRIPTION BY SITE	B-1
C: GLOSSARY OF ABBREVIATIONS	C-1
D: RAINFALL DATA	D-1
E: NATIONWIDE URBAN RUNOFF PROGRAM (NURP) DATA	E-1
F: WATER-QUALITY OBJECTIVES FOR AMBIENT SALT WATERS OF BAYS AND ESTUARIES (CALIFORNIA)	F-1

FIGURES

1. NAVSTA San Diego: Overview of sample sites	3
2a. Detailed view of sample sites: Sites 1-5	5
2b. Detailed view of sample sites: Sites 6-11	6
2c. Detailed view of sample sites: Sites 12-18	7
3. First-flush results for three metals	31
4. First-flush retainer: A management alternative	38

TABLES

1. Summary of storm events and types of samples collected	4
2. Laboratory analytical techniques for 16 Jan 90	9
3. Results of final flush for 16 Jan 90: unfiltered water	10
4. Laboratory analytical techniques for 31 Jan 90	16
5. Results of first flush for 31 Jan 90: filtered and unfiltered water	16
6. Laboratory analytical techniques for 19 Nov 90	17
7. Results of first flush for 19 Nov 90: filtered and unfiltered water	18

CONTENTS (Continued)

TABLES (Continued)

8.	Laboratory analytical techniques for 9 Jan 91	23
9.	Results of first flush for 9 Jan 91: filtered and unfiltered water	24
10.	Laboratory analytical techniques for 23-24 Oct 91	26
11.	Results of first flush for 23 Oct 91: unfiltered water	27
12.	Results of sediment grabs for 24 Oct 91	29
13.	Data from the nationwide urban runoff program (NURP) for three high interest metals	30
14.	Particulate/dissolved partitioning	34
15.	Particulate settling velocity in urban runoff	35
16.	Runoff pollutant limitations for petroleum refining	35

INTRODUCTION

UNIQUE ASPECTS OF STORM WATER RUNOFF

Mass loading comparisons of point-source and nonpoint-source loadings are often used to assess relative contributions from these sources. An environmental consequence not addressed by this approach is consideration of the first-flush contaminant pulse that poses acute toxicity risk to recipient biota. Point sources often provide a relatively steady flux of contaminants whereas nonpoint sources tend to be episodic pulses. The extent to which these flow regimes result in acute versus chronic impacts makes the environmental impact analysis of storm water runoff a more complex issue than if viewed as merely an incremental increase to point-source loadings. An understanding of the parameters that influence this variability in loading rates is necessary to devise sufficient monitoring programs, perform environmental risk assessment, and guide management efforts.

To ensure aquatic stewardship, a monitoring program must ensure that both worst-case acute loading as well as chronic exposure is maintained at safe levels. A major factor predicted to effect the chemical concentrations in runoff is the duration of the preceding interval without rain. This interval provides for the accumulation of contaminants in the water shed for subsequent entrainment in the runoff. This report contains data collected from a storm that followed nearly a half year without rain, as well as storms with shorter preceding rainless intervals. Inter-storm comparisons allow determination of this climatic factor on first-flush (worst-case) exposure. In addition to runoff-derived chemicals that deposit in sediments and release slowly, chronic effects may arise directly from the runoff during extended rain storms. This report includes samples taken on the third day of an extended storm.

A monitoring program should not only provide information on the magnitude of the problem but also on the specific sources and guidance for effective management. The monitoring described in this report included efforts to answer both these questions.

PRACTICAL SAMPLING CONSIDERATIONS

The preponderance of published runoff literature was derived from samples collected in riparian conditions and at large storm drains. Sampling in this manner helped the original research that determined mass loadings from large water sheds, did comparisons with point sources, and clarified that nonpoint sources are a significant contributor to aquatic pollution. Practical sampling approaches were refined for these conditions. For fine-scale spatial resolution of contaminant sources, sampling at the outlet from main conveyances is insufficient. For these conditions, a dispersed

sampling grid is needed. In addition, some facilities do not have a centralized conduit system, again necessitating a dispersed sampling grid. Since this was a methods development project, a study site with these problems was chosen to force the development and allow testing of new approaches to sample collecting.

This report documents a storm water runoff sampling strategy developed for and implemented at an industrial Navy base. This study site was selected because site characteristics pose sampling challenges that test the robustness of the sampling strategy. Additionally, current and historical industrial activity indicates potential chemical contamination concern.

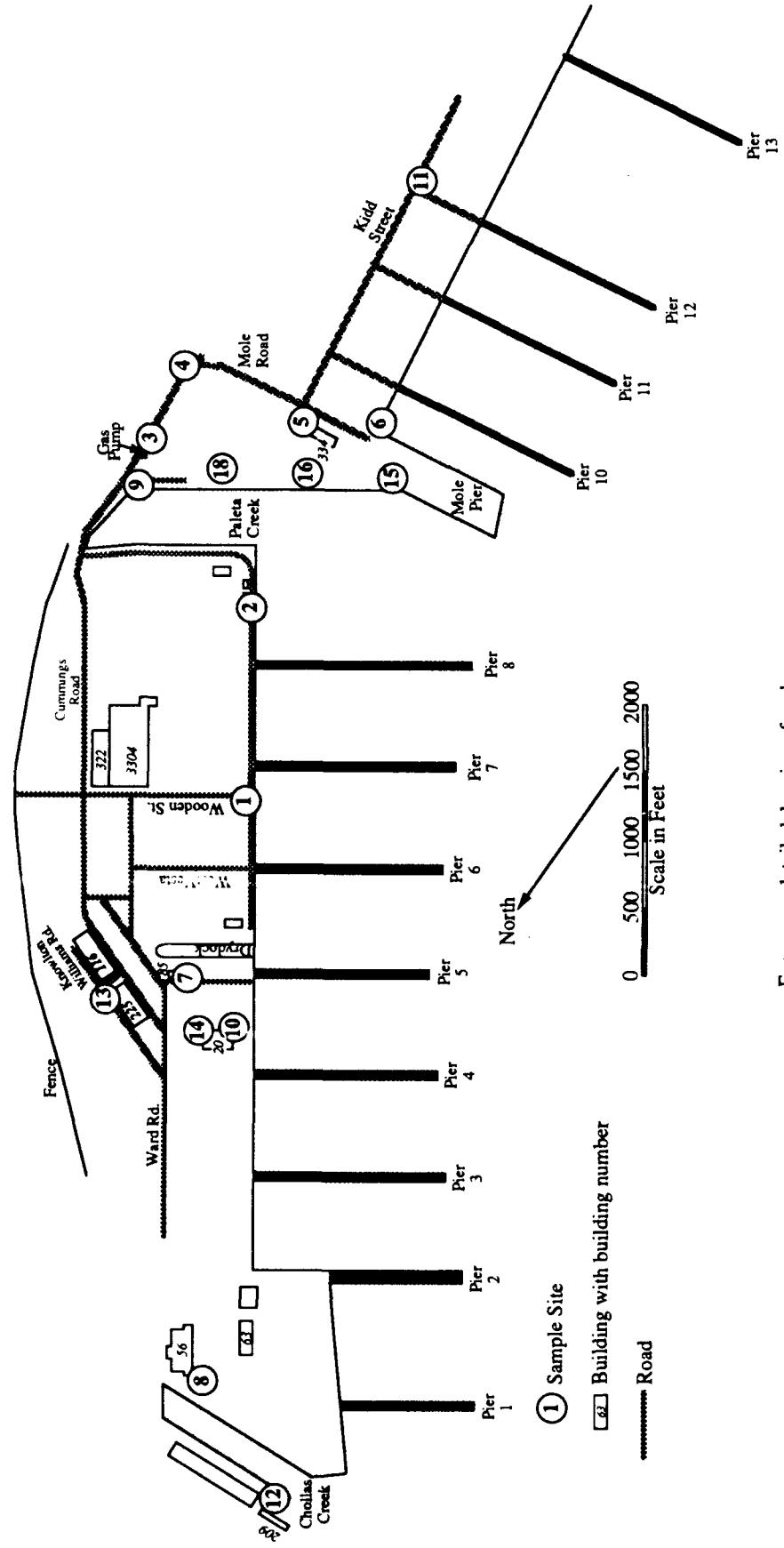
SITE DESCRIPTION

Naval Station San Diego (NAVSTA) in California is 976.8 acres of land adjacent to San Diego bay (figure 1). The entire shoreline is a vertical concrete quaywall that passes over 50 individual storm-drain outfalls and two ephemeral creeks. In addition, large areas also discharge as uncollected sheet flow over the quaywall. Most of the outfalls discharge at an intertidal elevation. Thus, the storm-sewer backfills and drains with the flood and ebb of the tide. NAVSTA is very flat with an extremely low slope within the storm-sewer system that results in extensive back-flooding at high tide.

The decentralized storm-sewer system consisting of uncollected sheet-flow discharge and numerous periodically submerged outfall pipes contributes to a difficult-to-sample situation. No single or small combination of sampling sites are representative of the entire NAVSTA. These challenges required an innovative and robust sampling program.

The surface permeability is extremely low—nearly the entire surface is either built, paved, or vehicle-packed sun-baked soil. Vegetation is nearly nonexistent. Measurement of base-wide surface permeability was beyond the scope of this project, but appendix A contains information on estimating surface permeability. For NAVSTA, after the first 0.01 inch or so to wet the surface, typically 70 to 80 percent of the precipitation should be expected to become runoff.

Many factors beyond the U.S. Navy's influence contributed to the severity of the contamination seen. For many reasons some of the data collected in this study can be assumed to be a worst-case for this type of Navy facility. San Diego has an arid climate whose infrequent rains allow surface contaminants to accumulate between rains. This effect is heightened because this study ran during the fourth and fifth year of a drought. In addition, San Diego has the fifth worst air pollution in the United States that contributes to dry and wet chemical fall-out.



For a more detailed drawing of each
sample site, see figure 2.

Figure 1. NAVSTA San Diego: Overview of sample sites.

GENERAL METHODS

The results from five storms are in this report. Methods for developing and testing were the primary purposes for this project and as a result a variety of sampling and analytical methods were used. A methods section is included with the results of the five storms. Several generally used methods will be described here and then included by reference when applicable during the methods description for each storm in the subsequent section.

Twelve sites (figures 1 and 2) representing a variety of different land uses within NAVSTA were sampled during one or more of the storm events. Appendix B contains sample-site descriptions. The types of samples collected for each storm are listed in table 1.

Table 1. Summary of storm events and types of samples collected.

Storm	Date	First Flush		Late Storm		Post Storm Sediment
		filtered	unfiltered	filtered	unfiltered	
1	16 Jan 90				X	
2	31 Jan 90	X	X			
3	19 Nov 90	X	X			
4	9 Jan 91	X	X			
5	23 Jan 91		X			X

First-flush samples were collected according to the method described by Gadbois (1991) using a 4-liter glass and a 4-liter polyethylene jug. These jugs were iced in the field before returning to the lab where the sample was shaken prior to and during redistribution into smaller sample jars for analyte analysis.

First-flush samplers were cleaned by washing with tap water, scrubbing with lab-grade soap, rinsing with deionized water, soaking in lab soap, rinsing with deionized water (DIW), soaking in 4N nitric acid, deionized water rinse, and air drying. This technique is described in detail by Gadbois (1991). Sample bottles were cleaned as prescribed in the analytical method.

Data are collected to answer the question of whether the runoff from NAVSTA contains sufficient contaminants and toxicity to pose an environmental risk, and if a risk is determined, to provide guidance for appropriate management.

Potential management requirements prompted an additional effort to quantify the extent of particulate binding of the contaminants. Some management techniques specifically target either the particulate or dissolved phase contaminants. A cursory examination of the particulate partitioning was addressed by filtering part of the samples under field and laboratory conditions. Both coarse and fine filtering was used. Filtered and unfiltered samples were analyzed and the particulate fraction calculated by difference between the two measures. The filtering process is described in the methods

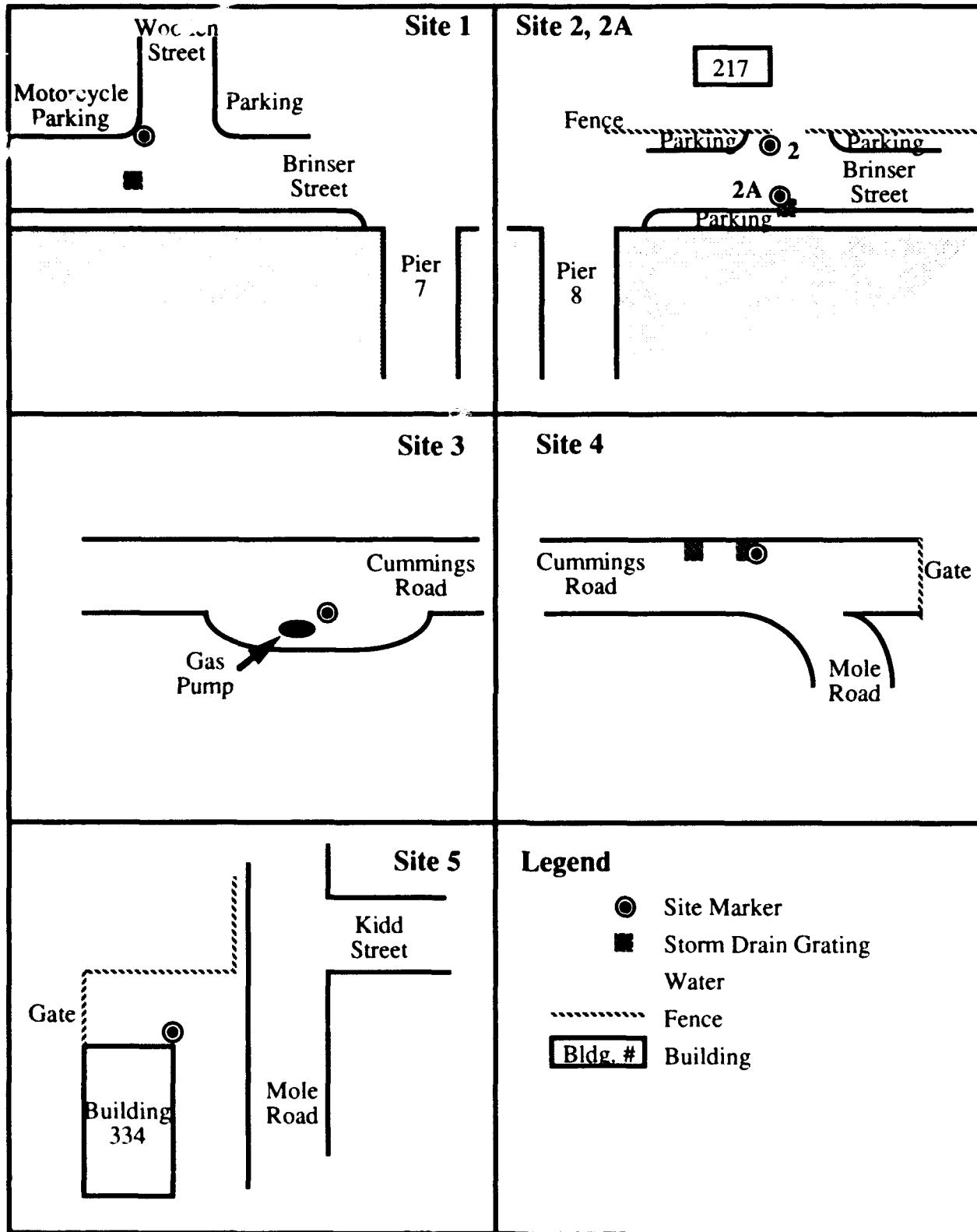


Figure 2a. Detailed view of sample sites: Sites 1-5.

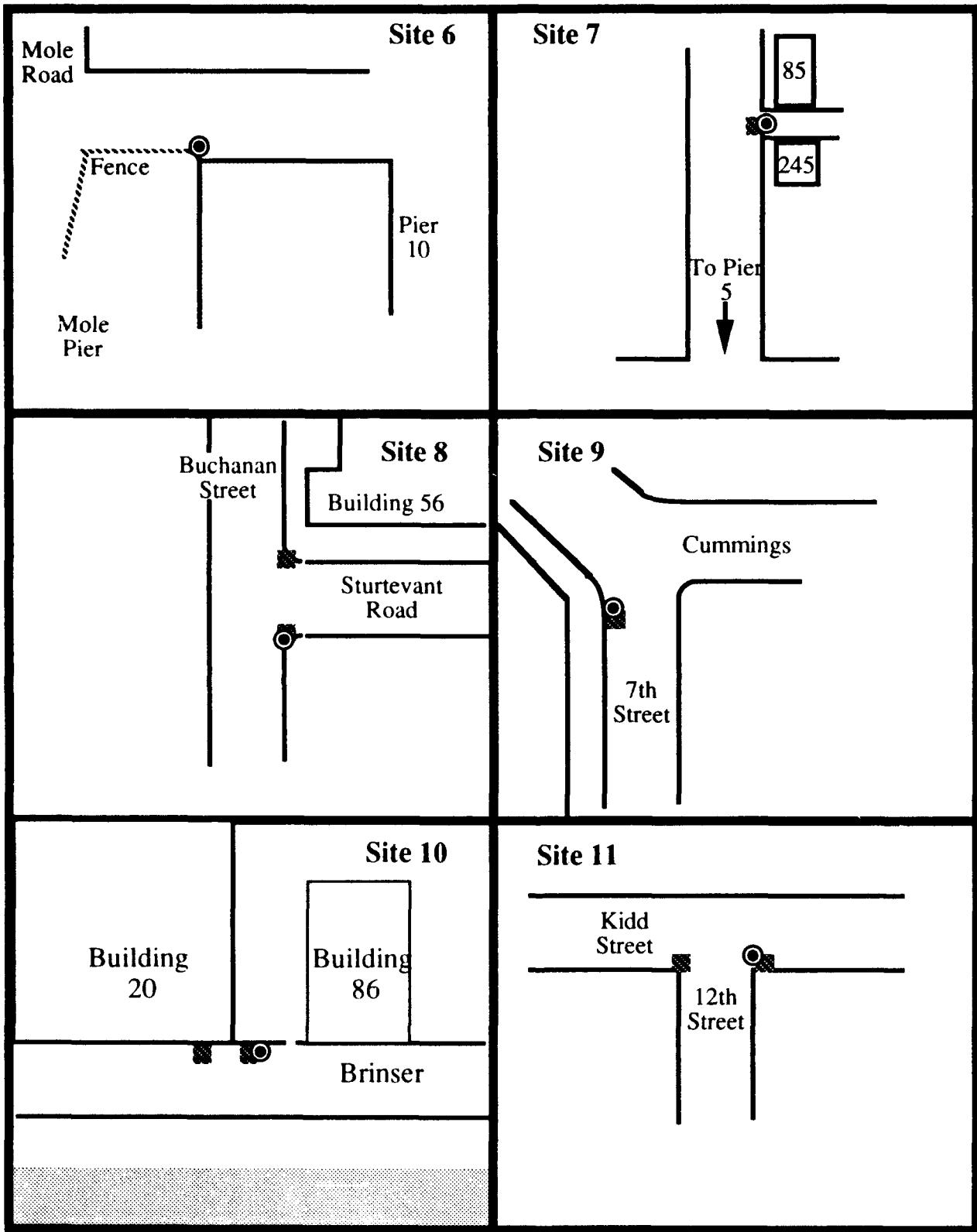


Figure 2b. Detailed view of sample sites: Sites 6-11.

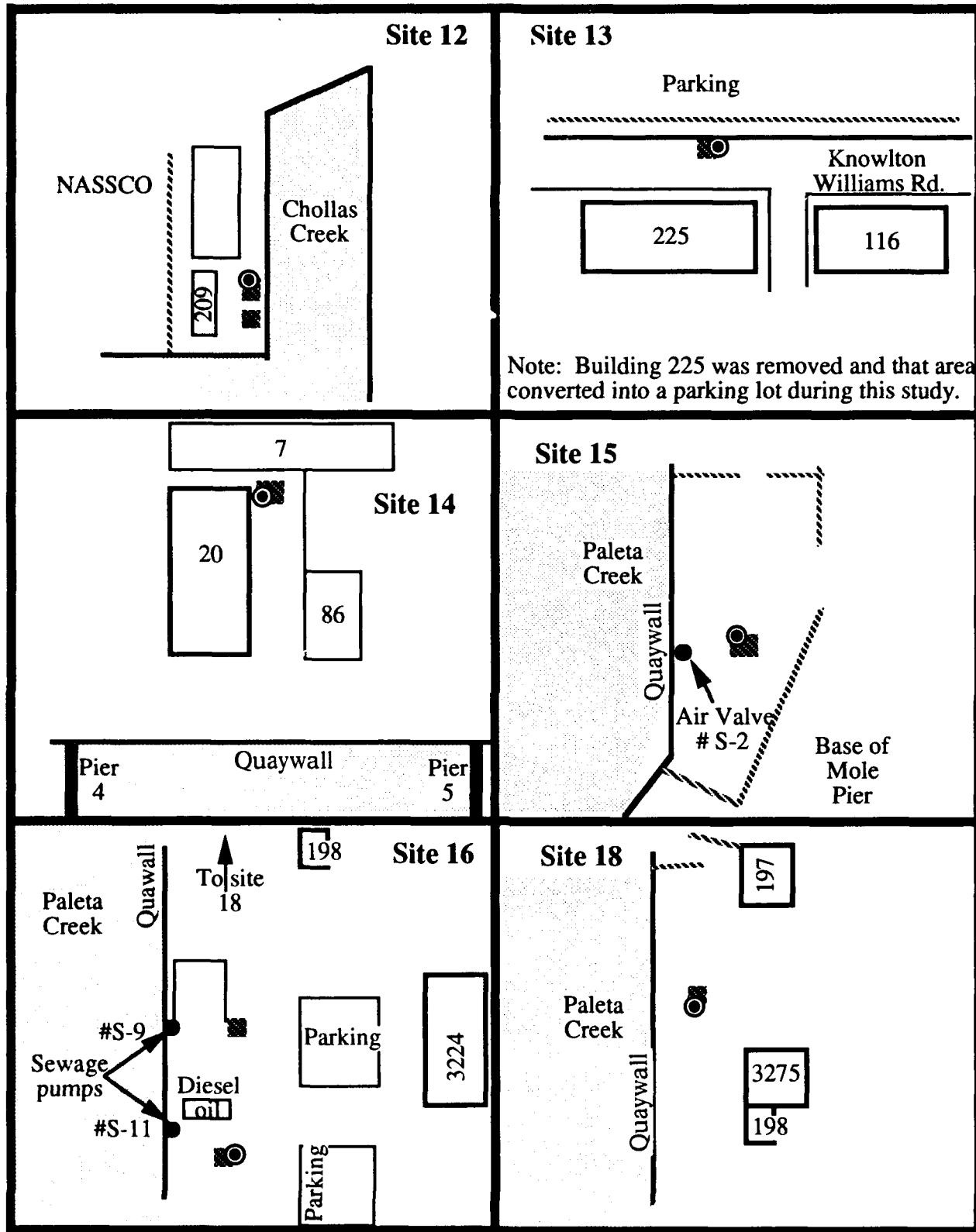


Figure 2c. Detailed view of sample sites: Sites 12-18.

sections for the specific storms. Acid was excluded from the preservation technique for all samples that were to be filtered to prevent premature digestion of contaminants out of the particulate phase.

Microtox samples were analyzed by NRaD. Results are reported as a dilution factor. For example, an EC₅₀ of 0.1 means a 50-percent reduction in light output (relative to the blank) was obtained using a solution containing 10-percent effluent and 90-percent blank. If no toxicity was present, the word "none" was used. If a slight toxicity was present but not enough to compute an EC₅₀, the word "slight" was used.

Chemical analysis was conducted by contract analytical labs. Two analytical labs were used. This allowed interlaboratory calibration of the results. The primary analytical lab met QA/QC protocol required under the EPA Superfund Contract Laboratory Protocol (CLP). The secondary analytical lab was state-certified by the California Department of Health. Additionally sample replicates (submitted "blindly" to the analytical lab as just another sample) were included to test the precision of the combined field/analytical technique. This technique allowed partitioning of the total variability between the sampling/analytical process and the true environmental component.

Since the primary interpretation of the results of this study is for use for variability assessments of site-to-site and storm-to-storm results, we needed to define the component of the variability that was an artifact from the sampling and analytical errors, and that artifact was a true environmental condition. To address this, numerous field samples were collected in duplicate or triplicate and submitted "blindly" to the lab. In general, the results were highly variable with the secondary analytical lab, but very precise for the primary analytical lab. For this and a variety of other reasons, including results of internal QA/QC procedures, the quality of the secondary analytical lab's data is questionable whereas the quality of the primary analytical lab is reaffirmed. The data from both labs are presented in the storm results section with an indication of which data came from which lab. In the general results and discussion section however, only the primary analytical lab's data are used since they are adequate to illustrate the general results and conclusions of this project.

SPECIFIC SURVEYS

FIRST SURVEY: 16 Jan 1990

Objective

The objective is to produce a scoping survey of a variety of sampling sites for initial assessment of intersite variability, and also to sample a best-case situation at these sites. Samples were also sent to two different analytical labs for interlab comparison.

Methods

These samples were collected early in the morning following a 3-day (holiday) weekend of light rain. These 3 days' worth of surface washing with minimal human activity for new addition can be considered a near best-case scenario for runoff from

NAVSTA. Appendix D contains rainfall data from the national weather service to support the interpretation of data from this and the other storm events studied in this report.

This is the only storm event sampled that did not involve first-flush samples collected with the first-flush sampler (Gadbois, 1991). Samples were a composite of grab samples collected during a 1-minute interval. At each site, all sample bottles were opened and lined-up. A plastic beaker-cup (washed with lab-grade soap, DIW rinsed, acid washed, DIW rinsed, air dried) was used to scoop aliquots of water. Water was dispensed to the sample bottles, an aliquot to each, then a second, third, etc., until full. As a result, bottles were incrementally filled at an even rate rather than one at a time. Thus they should be homogeneous.

Samples were submitted to two analytical labs, designated "primary" and "secondary" analytical labs.

Table 2. Laboratory analytical techniques for 16 Jan 90.

Analysis	Technique	Reference/Method
Primary Analytical Lab		
Chemical Oxygen Demand	Titrimetric	EPA 410.2
Oil & Grease	IR	EPA 413.2
Total Settleable Solids	Gravimetric	EPA 160.5
Total Kjeldahl Nitrogen	Colorimetric	EPA 351.2
Total Phosphate	ICAP	EPA 6010
Trace Organics		
Semivolatile Organics	GC/MS	EPA 8270
Antimony	ICAP	EPA 6010
Arsenic	AA/GF	EPA 7060
Beryllium	ICAP	EPA 6010
Cadmium	ICAP	EPA 6010
Chromium	ICAP	EPA 6010
Copper	ICAP	EPA 6010
Lead	AA/GF	EPA 7421
Mercury	AA/Cold Vapor	EPA 7471
Nickel	ICAP	EPA 6010
Selenium	AA/GF	EPA 7740
Silver	ICAP	EPA 6010
Thallium	AA/GF	EPA 7841
Zinc	ICAP	EPA 6010
Secondary Analytical Lab		
Total Suspended Solids		SMEWW 209C
Oil & Grease		EPA 413.2
Trace Organics		
Pesticides/PCBs		EPA 608
Semivolatile Organics		EPA 625
Metals		EPA SW-846

Abbreviations are in appendix C glossary.

Results

The reader is reminded that samples for these analyses were collected following a 3-day rain. Thus they may represent a near best case for contaminant levels and toxicity. See table 3.

Table 3. Results of final flush for 16 Jan 90: unfiltered water.

#=Primary Analytical Lab * =Secondary Analytical Lab

Analyte	Units	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Oil & Grease (replicate sample)	mg/l	19*	1.6#	13*	7*	45*	54*	0.9#
Total Settleable Solids	mg/l	0.4#	<0.5#	1.50#	0.8#	0.5#	1.4#	
Total Suspended Solids	ml/l	<0.5#	200*	<0.1#	0.8#	<0.1#	1.65#	
Antimony	mg/l	mg/l	<5*	<0.03#	320*	134*	570*	2700*
Arsenic	mg/l	<5*	<5*	0.007#	<0.03#	<0.03#	<0.03#	<5*
Beryllium	µg/l	<0.01*	<0.01*	<5#	0.007#	0.006#	0.009#	0.026*
Cadmium	µg/l	<10*	<10*	<5#	<0.01*	<0.01*	<0.01*	<10*
Chromium	mg/l	<10*	<10*	<5#	<5#	<5#	<5#	<10*
Copper (replicate sample)	mg/l	<0.02*	<0.02*	0.06#	0.03#	0.05#	0.06#	0.13*
Lead (replicate sample)	mg/l	0.06*	0.12#	0.26#	0.25#	0.25#	0.96#	0.65#
Mercury	mg/l	0.04*	0.04*	0.34#	0.24*	0.19#	1.1#	0.54#
Nickel	µg/l	0.16#	0.38#	1.6#	0.6#	0.23*	0.23*	0.20#
Selenium	µg/l	<0.14*	<0.14*	3*	20*	1.6#	1.1#	0.91*
Silver	µg/l	13*	0.02#	0.01#	<0.01#	2*	2*	8*
Thallium	mg/l	<0.03*	<0.03*	<2.0#	<0.03*	<0.03*	<2.0#	0.07*
Zinc (replicate sample)	mg/l	<10*	<10*	<0.01#	<2.0#	<10*	<10*	<10*
	mg/l	<10*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*
	mg/l	<2.5*	<2.5*	<2#	<2#	<2#	<2#	<2.5*
	mg/l	<2.5*	0.72#	0.72#	1.3#	1.4#	1.4#	1.9#
	mg/l	0.31*	1.2#	0.70*	1.3*	1.3*	1.3*	1.5#
	mg/l							12*

Table 3. Results of final flush for 16 Jan 90: unfiltered water (continued).

Analyte	Units	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Microtox 5-minute Total Organic Halides	EC ₅₀ µg/l		106*	Slight	None 62*	0.50	1.00	189* 380#
Chemical oxygen demand	mg/l				174#	88.2*	189*	82.8*
Total Kjeldahl Nitrogen	mg/l				1.8#	1.5#		
Total Phosphate as P	mg/l				1.2#	0.6#		
N-Nitrosodimethylamine	µg/l				<10#	<10#		
Aniline	µg/l				<14*	<14*		
Phenol	µg/l				<10#	<10#		
bis(2-Chloroethyl)ether	µg/l				<10#	<10#		
2-Chlorophenol	µg/l				<10#	<10#		
1,3-Dichlorobenzene	µg/l				<10#	<10#		
1,4-Dichlorobenzene	µg/l				<10#	<10#		
Benzyl alcohol	µg/l				<10#	<10#		
1,2-Dichlorobenzene	µg/l				<10#	<10#		
2-Methylphenol	µg/l				<10#	<10#		
bis(2-Chloroisopropyl)ether	µg/l				<10#	<10#		
4-Methylphenol	µg/l				<10#	<10#		
N-Nitroso-di-n-propylamine	µg/l				<10#	<10#		
Hexachloroethane	µg/l				<10#	<10#		
Nitrobenzene	µg/l				<10#	<10#		
Isophorone	µg/l				<10#	<10#		

Table 3. Results of final flush for 16 Jan 90: unfiltered water (continued).

Analyte	Units	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
2-Nitrophenol	µg/l					<10#	<10#	
2,4-Dimethylphenol	µg/l					<10#	<10#	
Benzoic acid	µg/l					<50#	<50#	<14*
bis(2-Chloroethoxy)methane	µg/l					<10#	<10#	<14*
2,4-Dichlorophenol	µg/l					<10#	<10#	<14*
1,2,4-Trichlorobenzene	µg/l					<10#	<10#	<14*
Naphthalene	µg/l					<10#	<10#	<14*
4-Chloroaniline	µg/l					<10#	<10#	<14*
Hexachlorobutadiene	µg/l					<10#	<10#	<14*
4-Chloro-3-methylphenol	µg/l					<10#	<10#	<14*
2-Methylnaphthalene	µg/l					<10#	<10#	<14*
Hexachlorocyclopentadiene	µg/l					<10#	<10#	<14*
2,4,6-Trichlorophenol	µg/l					<10#	<10#	<14*
2,4,5-Trichlorophenol	µg/l					<50#	<50#	<14*
2-Choronaphthalene	µg/l					<10#	<10#	<14*
2-Nitroaniline	µg/l					<50#	<50#	<70*
Dimethylphthalate	µg/l					<10#	<10#	<14*
Acenaphthylene	µg/l					<10#	<10#	<14*
3-Nitroaniline	µg/l					<50#	<50#	<70*

Table 3. Results of final flush for 16 Jan 90: unfiltered water (continued).

Analyte	Units	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Acenaphthene	µg/l					<10#	<10#	<14*
2,4-Dinitrophenol	µg/l					<50#	<50#	<50#
4-Nitropheno1	µg/l					<50#	<70*	<70*
Dibenzofuran	µg/l					<10#	<50#	<70*
2,4-Dinitrotoluene	µg/l					<10#	<10#	<14*
2,6-Dinitrotoluene	µg/l					<10#	<10#	<14*
Diethylphthalate	µg/l					<10#	<10#	<14*
4-Chlorophenyl-phenylether	µg/l					<10#	<10#	<14*
Fluorene	µg/l					<10#	<10#	<14*
4-Nitroaniline	µg/l					<50#	<50#	<70*
4,6-Dinitro-2-methylphenol	µg/l					<50#	<50#	<70*
N-Nitrosodiphenylamine	µg/l					<10#	<10#	<14*
4-Bromophenyl-phenylether	µg/l					<10#	<10#	<14*
Hexachlorobenzene	µg/l					<10#	<10#	<14*
Pentachloropheno1	µg/l					<50#	<50#	<70*
Phenanthrene	µg/l					<10#	<10#	<14*
Anthracene	µg/l					<10#	<10#	<14*
Di-n-butylphthalate	µg/l					<10#	<10#	<14*
Fluoranthene	µg/l					<10#	<10#	<14*

Table 3. Results of final flush for 16 Jan 90: unfiltered water (continued).

Analyte	Units	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Benzidine	µg/l					<100#	<100#	<70*
Pyrene	µg/l					<10#	<10#	<10#
Butylbenzylphthalate	µg/l					<10#	<14*	<14*
3,3-Dichlorobenzidine	µg/l					<20#	<20#	<10#
Benzo(a)anthracene	µg/l					<10#	<10#	<14*
bis(2-Ethylhexyl)phthalate	µg/l					1.0#	1.0#	3.1#
Chrysene	µg/l					<10#	<10#	<14*
di-n-Octylphthalate	µg/l					<10#	<10#	<14*
Benzo(b)fluoranthene	µg/l					<10#	<10#	<14*
Benzo(k)fluoranthene	µg/l					<10#	<10#	<14*
Benzo(a)pyrene	µg/l					<10#	<10#	<10#
Indeno(1,2,3-cd)pyrene	µg/l					<10#	<10#	<14*
Dibenz(a,h)anthracene	µg/l					<10#	<10#	<14*
Benzo(g,h,i)perylene	µg/l					<10#	<10#	<14*
alpha-BHC	µg/l					<0.05*	<0.05*	<0.05*
beta-BHC	µg/l					<0.05*	<0.05*	<0.05*
gamma-BHC (Lindane)	µg/l					<0.05*	<0.05*	<0.05*
delta-BHC	µg/l					<0.05*	<0.05*	<0.05*
Heptachlor	µg/l					<0.05*	<0.05*	<0.05*
Aldrin	µg/l					<0.05*	<0.05*	<0.05*
Heptachlor Epoxide	µg/l					<0.05*	<0.05*	<0.05*
Endosulfan I	µg/l					<0.10*	<0.10*	<0.10*
4,4-DDE	µg/l							

Table 3. Results of final flush for 16 Jan 90: unfiltered water (continued).

Analyte	Units	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Dieldrin	µg/l				<0.10*			
Endrin	µg/l				<0.10*			
Endosulfan II	µg/l				<0.10*			
4,4-DDD	µg/l				<0.10*			
Endrin Aldehyde	µg/l				<0.10*			
Endosulfan Sulfate	µg/l				<0.10*			
4,4-DDT	µg/l				<0.10*			
Methoxychlor	µg/l				<0.50*			
Chlordane	µg/l				<0.50*			
Toxaphene	µg/l				<1.00*			
Aroclor-1016	µg/l				<0.50*			
Aroclor-1221	µg/l				<0.50*			
Aroclor-1232	µg/l				<0.50*			
Aroclor-1242	µg/l				<0.50*			
Aroclor-1248	µg/l				<0.50*			
Aroclor-1254	µg/l				<1.00*			
Aroclor-1260	µg/l				<1.00*			

SECOND SURVEY: 31 Jan 1990

Objective

The objective of this sampling was to quantify the portion of the pollutants bound in the particulate phase, to identify additional contaminant hot spots, and to compare the first-flush data of this sampling to the post-3-day rain samples collected on 16 Jan 90.

Methods

This survey measured first-flush contaminants. Samples were collected according to Gadbois (1991) using a 1-gallon glass and a 1-gallon polyethylene jug. Samples were analyzed by the secondary analytical lab.

The gallon amber glass jar of composite sample was inverted and shaken thoroughly and then quickly poured into sample jars to measure total contaminants. Part of the composite sample was also filtered with a Whatman #41H "Ashless" filter in the field (fast filtering, intended for gelatinous or large particle precipitates). The filtered water was thereafter analyzed in the same manner as the unfiltered samples.

Table 4. Laboratory analytical techniques for 31 Jan 90.

Analysis	Technique	Reference/Method
Secondary Analytical Lab		SMEWW 209C
Total Suspended Solids		EPA 413.2
Oil & Grease		EPA 9020
Total Organic Halides		

Results

Table 5. Results of first flush for 31 Jan 90: filtered and unfiltered water.

Analyte	Units	Site 2A	Site 6	Site 8	Site 9	Site 10	Site 11
Oil & Grease (replicate)	mg/l	14	7	3	2	2	3
(0.45- μ filtered) (replicate)	mg/l	8	8	2	2	<1	3
Total Suspended Solids (replicate)	mg/l	3	36	2	3	22	19
(0.45- μ filtered) (replicate)	mg/l	10	22	4	17	8	15
Total Organic Halides (replicate)	mg/l	0.47	0.16	0.04	0.22	0.30	0.13
(0.45- μ filtered) (replicate)	mg/l	0.45	0.14	0.05	0.18	0.26	0.09
	mg/l						0.15

THIRD SURVEY: 19 Nov 1990

Objective

The objective is to quantify the contaminant levels in the first flush following an extended dry period and to test additional analytical methods.

Methods

This survey measured first flush contaminants. Samples were collected according to Gadbois (1991) using a 1-gallon glass and a 1-gallon polyethylene jug. Samples were analyzed by the primary analytical lab. Sample filtering was conducted at the analytical lab using a $0.45\text{-}\mu$ filter. No acids were used to preserve samples to be filtered.

Table 6. Laboratory analytical techniques for 19 Nov 90.

Analysis	Technique	Reference/Method
Primary Analytical Lab		
Total Petroleum Hydrocarbons	IR	EPA 418.1
Total Suspended Solids	Gravimetric	EPA 160.2
Total Kjeldahl Nitrogen	Colorimetric	EPA 351.2
Total Organic Phosphate	Colorimetric	424 Standard
Ortho Phosphate	Colorimetric	EPA 365.1
Trace Organics		
Halogenated Volatile Organics	GC/ELCD	EPA 8010
Aromatic Volatile Organics	GC/PID	EPA 8020
Antimony	ICAP	EPA 6010
Arsenic	AA/GF	EPA 7060
Beryllium	ICAP	EPA 6010
Cadmium	ICAP	EPA 6010
Chromium	ICAP	EPA 6010
Copper	ICAP	EPA 6010
Lead	AA/GF	EPA 7421
Mercury	AA/Cold Vapor	EPA 7471
Nickel	ICAP	EPA 6010
Selenium	AA/GF	EPA 7740
Silver	ICAP	EPA 6010
Thallium	AA/GF	EPA 7841
Zinc	ICAP	EPA 6010

Results

Table 7. Results of first flush for 19 Nov 90: filtered and unfiltered water.

Analyte	Units	Site 6	Site 7	Site 10	Site 11	Site 12	Site 13	Site 14
Microtox 5-minute (replicate)	EC ₅₀	0.030	0.29	0.20	0.20	0.12	0.31	>1.0
(replicate)		0.029	0.25	0.21	0.28	0.13	0.36	0.96
(replicate)		0.038	0.25	0.18	0.36	0.15		0.71
(replicate)		0.040	0.18	0.25	0.36	0.12		0.60
Total Petro Hydro (0.45-μ filtered) (replicate)	mg/l	2.3	13	<0.05	0.66	0.89	1.0	0.08
	mg/l	2.7						
	mg/l	1.5	1.1					
	mg/l	1.5						
Total Suspended Solids (replicate) (replicate)	mg/l	175	230	265	150	390	280	138
	mg/l	275	410	270	150	255		140
	mg/l							200
Ortho Phosphate (0.45-μ filtered) (replicate)	mg/l	5.1	<0.50	1.1	0.90	0.60		0.50
	mg/l	5.1						
	mg/l	3.8	<0.50	0.60	<0.50	0.50		<0.50
	mg/l							
Total Organic Phosphate (0.45-μ filtered) (replicate)	mg/l	<0.25	<0.25	<0.25	<0.25	<0.25		0.30
	mg/l	0.60	0.36	<0.25	<0.25	<0.25		0.41
	mg/l							
Total Kjeldahl Nitrogen (0.45-μ filtered) (replicate)	mg/l	34.5	18.1	20.0	30.1	7.1		16.3
	mg/l	64.1	11.6	17.8	27.7	4.8		11.8
	mg/l					4.7		
Silver (0.45-μ filtered) (replicate)	mg/l	<0.01	<0.01	<0.01	<0.01	0.01		<0.01
	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01
	mg/l							
Arsenic (0.45-μ filtered) (replicate)	mg/l	0.043	<0.002	<0.002	0.13	0.004		<0.002
	mg/l	0.03	<0.002	<0.004	0.12	0.002		<0.002
	mg/l					0.12		

Table 7. Results of first flush for 19 Nov 90: filtered and unfiltered water (continued).

Analyte	Units	Site 6	Site 7	Site 10	Site 11	Site 12	Site 13	Site 14
Beryllium (replicate) (0.45- μ filtered)	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	mg/l							
	mg/l							
Cadmium (replicate) (0.45- μ filtered)	mg/l	0.11	0.03	0.02	0.02	0.007	<0.005	0.02
	mg/l	0.11	0.03	0.02	0.02	0.006	<0.005	0.02
	mg/l							
Chromium (replicate) (0.45- μ filtered)	mg/l	0.10	0.05	0.06	0.04	0.09	0.05	0.04
	mg/l	0.06	0.02	0.03	0.03	0.01	0.01	0.02
	mg/l							
Copper (replicate) (0.45- μ filtered)	mg/l	18.3	2.1	0.78	1.0	4.3	0.66	0.67
	mg/l	16.1	1.7	0.62	1.2	1.8	0.48	0.57
	mg/l							
Mercury (replicate) (0.45- μ filtered)	μ g/l	<0.5	0.7	<0.5	<0.5	<0.5	<0.5	1.0
	μ g/l	<0.5	<0.5	0.5	<0.5	0.5	<0.5	0.7
	μ g/l							
Nickel (replicate) (0.45- μ filtered)	mg/l	0.32	0.12	0.11	0.15	0.07	0.05	0.12
	mg/l	0.29	0.10	0.09	0.14	0.03	0.03	0.10
	mg/l							
Lead (replicate) (0.45- μ filtered)	mg/l	0.35	0.26	0.31	0.14	0.68	0.16	0.17
	mg/l	0.17	0.059	0.032	0.14	0.066	0.037	0.022
	mg/l							0.039

Table 7. Results of first flush for 19 Nov 90: filtered and unfiltered water (continued).

Analyte	Units	Site 6	Site 7	Site 10	Site 11	Site 12	Site 13	Site 14
Chloroform (replicate)	$\mu\text{g/l}$	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40
Chloromethane (replicate)	$\mu\text{g/l}$	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40
Dibromochloromethane (replicate)	$\mu\text{g/l}$	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40
1,2-Dichlorobenzene (replicate)	$\mu\text{g/l}$	<1.00	<0.50	<0.50	<0.50	<0.50	<0.50	<1.00
1,3-Dichlorobenzene (replicate)	$\mu\text{g/l}$	<1.00	<0.50	<0.50	<0.50	<0.50	<0.50	<1.00
1,4-Dichlorobenzene (replicate)	$\mu\text{g/l}$	<1.00	<0.50	<0.50	<0.50	<0.50	<0.50	<1.00
Dichlorodifluoromethane (replicate)	$\mu\text{g/l}$	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40
1,1-Dichloroethane (replicate)	$\mu\text{g/l}$	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40
1,2-Dichloroethane (replicate)	$\mu\text{g/l}$	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40
1,1-Dichloroethene (replicate)	$\mu\text{g/l}$	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40
Cis-1,2-Dichloroethene (replicate)	$\mu\text{g/l}$	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40
Trans-1,2- Dichloroethene (replicate)	$\mu\text{g/l}$	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40
1,2-Dichloropropane (replicate)	$\mu\text{g/l}$	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40

Table 7. Results of first flush for 19 Nov 90: filtered and unfiltered water (continued).

Analyte	Units	Site 6	Site 7	Site 10	Site 11	Site 12	Site 13	Site 14
Antimony (replicate) (0.45- μ filtered)	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Selenium (replicate) (0.45- μ filtered)	mg/l	0.006	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
	mg/l	<0.004	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
	mg/l	<0.004	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Thallium (replicate) (0.45- μ filtered)	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Zinc (replicate) (0.45- μ filtered)	mg/l	49.5	11.8	7.3	3.5	13.0	3.6	29.9
	mg/l	47.7	10.8	6.7	3.5	9.4	2.9	26.9
	mg/l	47.7	10.8	6.7	3.4			
Benzene (replicate)	μ g/l	<1.00	<0.50	<0.50	<0.50	<0.50	<0.50	<1.00
Bromodichloromethane (replicate)	μ g/l	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40
Bromoform (replicate)	μ g/l	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40
Bromomethane (replicate)	μ g/l	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40
Carbon Tetrachloride (replicate)	μ g/l	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40
Chlorobenzene (replicate)	μ g/l	<1.00	<0.50	<0.50	<0.50	<0.50	<0.50	<1.00
Chloroethane (replicate)	μ g/l	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<0.40

Table 7. Results of first flush for 19 Nov 90: filtered and unfiltered water (continued).

Analyte	Units	Site 6	Site 7	Site 10	Site 11	Site 12	Site 13	Site 14
Cis-1,3-Dichloropropene (replicate)	µg/l	<0.40	<0.20	<0.20	<0.20	<0.20 <0.20	<0.20	<0.40
Trans-1,3-Dichloropropene (replicate)	µg/l	<0.40	<0.20	<0.20	<0.20	<0.20 <0.20	<0.20	<0.40
Ethylbenzene (replicate)	µg/l	<1.00	<0.50	<0.50	<0.50	<0.50 <0.50	<0.50	<1.00
Methylene Chloride (replicate)	µg/l	<4.0	<2.0	<2.0	<2.0	<2.0 <2.0	<2.0	<4.0
1,1,2,2-Tetrachloroethane (replicate)	µg/l	<0.40	<0.20	<0.20	<0.20	<0.20 <0.20	<0.20	<0.40
Tetrachloroethene (replicate)	µg/l	<0.40	<0.20	<0.20	<0.20	<0.20 <0.20	<0.20	<0.40
Toluene (replicate)	µg/l	<1.00	<0.50	<0.50	<0.50	<0.50 <0.50	<0.50	<1.00
1,1,1-Trichloroethane (replicate)	µg/l	<0.40	<0.20	<0.20	<0.20	<0.20 <0.20	<0.20	<0.40
1,1,2-Trichloroethane (replicate)	µg/l	<0.40	<0.20	<0.20	<0.20	<0.20 <0.20	<0.20	<0.40
Trichloroethene (replicate)	µg/l	<0.40	<0.20	<0.20	<0.20	<0.20 <0.20	<0.20	<0.40
Trichlorofluoromethane (replicate)	µg/l	<4.0	<2.0	<2.0	<2.0	<2.0 <2.0	<2.0	<4.0
Vinyl Chloride (replicate)	µg/l	<0.40	<0.20	<0.20	<0.20	<0.20 <0.20	<0.20	<0.40
Xylenes (Total) (replicate)	µg/l	<2.0	<1.0	<1.0	<1.0	<1.0 <1.0	<1.0	<2.0

FOURTH SURVEY: 9 Jan 1991

Objective

The objective is to quantify the contaminant levels in the first flush following a short period without rain to determine how rapidly the surface of the watershed accumulates contaminants between storms.

Methods

This survey measured first-flush contaminants. Samples were collected in the first-flush sampler (Gadbois, 1991) using a 1-gallon glass and a 1-gallon polyethylene jug. Samples were analyzed by the primary analytical lab. Sample filtering was conducted at the analytical lab using a $0.45\text{-}\mu$ filter. No acids were used to preserve samples to be filtered.

During this sampling, we noted that if collection funnels were not hanging nearly vertical, inflowing water would flow into one jug prior to filling the other jug. This filling became apparent because, at one site, one of the sample jugs collected from what must have been a very brief pulse of turbid water. The pulse was completed by the time the other jug began filling. A visual turbidity difference in the two jugs was observed. This difference prompted taking a sample for microtox analysis from both the glass and the polyethylene bottles at several of the sites for comparison. The results will show that measurably different toxicity was found at two of the three sites analyzed in this split manner.

Table 8. Laboratory analytical techniques for 9 Jan 91.

Analysis	Technique	Reference/Method
Primary Analytical Lab		
Total Petroleum Hydrocarbons	IR	EPA 418.1
Total Suspended Solids	Gravimetric	EPA 160.2
Total Kjeldahl Nitrogen	Colorimetric	EPA 351.2
Total Organic Phosphate	Colorimetric	424 Standard
Ortho Phosphate	Colorimetric	EPA 365.1
Trace Organics		
Halogenated Volatile Organics	GC/ELCD	EPA 8010
Aromatic Volatile Organics	GC/PID	EPA 8020
Antimony	ICAP	EPA 6010
Arsenic	AA/GF	EPA 7060
Beryllium	ICAP	EPA 6010
Cadmium	ICAP	EPA 6010
Chromium	ICAP	EPA 6010
Copper	ICAP	EPA 6010
Lead	AA/GF	EPA 7421
Mercury	AA/Cold Vapor	EPA 7471
Nickel	ICAP	EPA 6010
Selenium	AA/GF	EPA 7740
Silver	ICAP	EPA 6010
Thallium	AA/GF	EPA 7841
Zinc	ICAP	EPA 6010

Results

Table 9. Results of first flush for 9 Jan 91: filtered and unfiltered water.

Analyte	Units	Site 6	Site 7	Site 10	Site 11	Site 13	Site 14
Microtox (glass jar) (poly jar)	EC ₅₀	slight 0.45	slight slight	slight	0.67	slight	slight 0.13
Total Petro Hydro (0.45-μ filtered)	mg/l	5	16	7	12	6	12
Total Susp Solids (replicate)	mg/l	0.06	0.2	3	0.5	1	0.3
Total Susp Solids (replicate)	mg/l	250	485	195	220	1060	325
Ortho Phos (0.45-μ filtered)	mg/l	235	645	170	230	1670	240
Ortho Phos (0.45-μ filtered)	mg/l	<0.25	<0.25	0.35	<0.25	1.8	1.5
Total Phos (0.45-μ filtered)	mg/l	<0.25	<0.25	<0.25	<0.25	1.9	1.8
Total Kjeldahl Nitrogen (0.45-μ filtered)	mg/l	<1.0	0.52	0.58	0.45	3.7	2.0
Total Kjeldahl Nitrogen (0.45-μ filtered)	mg/l	4.6	2.8	7.3	2.8	2.3	14.3
Silver (0.45-μ filtered)	mg/l	3.6	1.6	5.5	2.1	0.86	10.3
Silver (0.45-μ filtered)	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Arsenic (0.45-μ filtered)	mg/l	0.004	<0.002	<0.002	<0.002	0.014	<0.002
Beryllium (0.45-μ filtered)	mg/l	<0.002	<0.002	<0.002	<0.002	0.005	<0.002
Cadmium (0.45-μ filtered)	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Chromium (0.45-μ filtered)	mg/l	0.008	0.009	0.006	0.006	0.010	0.02
Chromium (0.45-μ filtered)	mg/l	<0.005	<0.005	<0.005	<0.005	0.006	0.02
Copper (0.45-μ filtered)	mg/l	0.05	0.05	0.04	0.04	0.05	0.06
Copper (0.45-μ filtered)	mg/l	<0.01	<0.01	0.01	<0.01	0.02	0.03
Copper (0.45-μ filtered)	mg/l	1.4	0.62	0.32	1.8	0.37	0.60
Mercury (0.45-μ filtered)	mg/l	0.74	0.16	0.22	0.55	0.33	0.50
Mercury (0.45-μ filtered)	mg/l	0.0086	0.0006	<0.0005	<0.0005	0.0005	0.0020
Nickel (0.45-μ filtered)	mg/l	0.0064	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Nickel (0.45-μ filtered)	mg/l	0.03	0.03	0.03	0.03	0.05	0.05
Lead (0.45-μ filtered)	mg/l	0.02	<0.01	0.02	0.01	0.03	0.05
Lead (0.45-μ filtered)	mg/l	0.21	0.50	0.18	0.61	0.25	0.30
Antimony (0.45-μ filtered)	mg/l	0.007	0.007	0.006	0.011	0.14	0.21
Antimony (0.45-μ filtered)	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	0.03
Selenium (0.45-μ filtered)	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Selenium (0.45-μ filtered)	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Thallium (0.45-μ filtered)	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Thallium (0.45-μ filtered)	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Zinc (0.45-μ filtered)	mg/l	2.5	2.5	1.7	5.3	1.6	27.8
Zinc (0.45-μ filtered)	mg/l	1.7	1.1	1.4	3.6	1.6	27.2
Benzene	μg/l	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Bromodichloromethane	μg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Bromoform	μg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Bromomethane	μg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Carbon Tetrachloride	μg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Chlorobenzene	μg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Chloroethane	μg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Chloroform	μg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Chloromethane	μg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Dibromochloromethane	μg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20

Table 9. Results of first flush for 9 Jan 91: filtered and unfiltered water (continued).

Analyte	Units	Site 6	Site 7	Site 10	Site 11	Site 13	Site 14
1,2-Dichlorobenzene	µg/l	<0.50	<0.50	<0.50	<0.50	<0.50	0.59
1,3-Dichlorobenzene	µg/l	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
1,4-Dichlorobenzene	µg/l	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Dichlorodifluoromethane	µg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
1,1-Dichloroethane	µg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
1,2-Dichloroethane	µg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
1,1-Dichloroethene	µg/l	1.5	<0.20	<0.20	<0.20	<0.20	<0.20
Cis-1,2-Dichloroethene	µg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Trans-1,2-Dichloroethene	µg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
1,2-Dichloropropane	µg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Cis-1,3-Dichloropropene	µg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Trans-1,3-Dichloropropene	µg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Ethylbenzene	µg/l	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Methylene Chloride	µg/l	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
1,1,2,2-Tetrachloroethane	µg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Tetrachloroethene	µg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Toluene	µg/l	1.1	<0.50	<0.50	<0.50	<0.50	<0.50
1,1,1-Trichloroethane	µg/l	15	<0.20	<0.20	<0.20	<0.20	<0.20
1,1,2-Trichloroethane	µg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Trichloroethene	µg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Trichlorofluoromethane	µg/l	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Vinyl Chloride	µg/l	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Xylenes (Total)	µg/l	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

FIFTH SURVEY: 23-24 Oct 1991

Objective

The objective is to further expand the data set of first-flush events for between-storm comparisons, perform initial screening at several sites to see if contaminant residues are at high levels in the sediment that accumulates in the man-hole, and conduct an initial screening of contaminants in the material removed by current street sweeping operations.

Methods

This survey measured first-flush contaminants. Samples were collected according to Gadbois (1991) using a 1-gallon glass and a 1-gallon polyethylene jug. Samples were analyzed by the primary analytical lab. No sample filtering was done.

A single glass sample jar was used for all sediment chemistry. This jar was filled by using numerous aliquots from a small stainless-steel scoop. A second jar was filled the same way and analyzed for grain size.

Table 10. Laboratory analytical techniques for 23-24 Oct 91.

Analysis	Technique	Reference/Method
Primary Analytical Lab		
Grain Size	Sieve/Hydrometer	ASTM D 422
Total Petroleum Hydrocarbons	IR	EPA 418.1
Oil & Grease	IR	EPA 413.2
Total Suspended Solids	Gravimetric	EPA 160.2
Total Kjeldahl Nitrogen	Colorimetric	EPA 351.2
Total Organic Phosphate	Colorimetric	EPA 365.1, ASTM 424.C
Total Organic Carbon	TOC Analyzer	EPA 9060
Total Organic Halides	TOX Analyzer	EPA 9020
Trace Organics		
Aromatic Volatile Organics	GC/PID	EPA 8020
PCBs	GC/ECD	EPA 8080
PAHs	HPLC	EPA 8010
Arsenic	AA/GF	EPA 7060
Cadmium	ICAP	EPA 6010
Chromium	ICAP	EPA 6010
Copper	ICAP	EPA 6010
Lead (Sediment)	AA/GF	EPA 7421
Lead (Water)	AA/GF	EPA 6010
Mercury	AA/Cold Vapor	EPA 7471
Nickel	ICAP	EPA 6010
Zinc	ICAP	EPA 6010

Results

Table 11. Results of first flush for 23 Oct 91: unfiltered water.

Analyte	Units	Site 6	Site 10	Site 11	Site 12	Site 15	Site 16	Site 18
Total Kjeldahl Nitrogen (replicate)	mg/l	10.4	10.5	12.9	7.4	15.8	29.4	30.4
Total Organic Phosphate (replicate)	mg/l	0.42	0.10	0.75	0.50	0.47	0.34	0.41
Total Suspended Solids (replicate)	mg/l	<20	220	<20	<20	20	120	26
Total Petro Hydro (replicate)	mg/l	<20	<20	<20	<20	60	22	26
Oil & Grease (replicate)	mg/l	2.6		<0.2	0.8	0.6	3.0	
Total Organic Halides (replicate)	mg/l	3.4		<0.05	8.4	1.1		
Arsenic (replicate)	mg/l	8.6		2.8	5.2	6.7		
Cadmium (replicate)	mg/l	7.6		1.5	1.7	9.9	6.8	2.0
Chromium (replicate)	mg/l	0.004		0.53	0.010	0.005	0.008	0.006
Copper (replicate)	mg/l	0.03		0.03	0.006	0.009	0.07	0.007
Mercury (replicate)	mg/l	0.04		0.03	0.04	0.05	0.12	0.15
Nickel (replicate)	mg/l	2.9		1.9	0.73	2.3	2.9	0.06
Lead (replicate)	mg/l	<0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Zinc (replicate)	mg/l	0.11		0.09	0.09	0.06	0.17	0.14
Naphthalene	µg/l	0.12		0.13	0.26	0.70	0.29	0.14
Acenaphthylene	µg/l	19.6		9.1	2.7	17.9	10.9	1.2
Acenaphthene	µg/l	<0.5		<0.5	<0.5	<0.5	<0.5	5.0
Fluorene	µg/l	<1		<1	<1	<1	<1	<10
Phenanthrene	µg/l	<1		<1	<1	<1	<1	<10
Anthracene	µg/l	<0.1		<0.1	<0.1	<0.1	<0.1	11
Fluoranthene	µg/l	0.18		0.15	0.86	0.61	1.2	65
Pyrene	µg/l	<0.05		<0.05	<0.05	<0.05	0.085	7.1
Benzo(a)Anthracene	µg/l	0.24		0.23	1.3	1.5	3.4	110
	µg/l	0.13		0.18	0.65	0.68	1.9	64
	µg/l	<0.1		<0.1	<0.1	<0.1	0.27	7.0

Table 11. Results of first flush for 23 Oct 91: unfiltered water (continued).

Analyte	Units	Site 6	Site 10	Site 11	Site 12	Site 15	Site 16	Site 18
Chrysene	µg/l	<0.1	<0.1	<0.1	0.36	0.57	1.1	17
Benzo(b)Fluoranthene	µg/l	<0.1	<0.1	<0.1	0.16	0.35	0.68	7.2
Benzo(k)Fluoranthene	µg/l	<0.1	<0.1	<0.1	<0.1	0.13	0.25	3.5
Benzo(a)Pyrene	µg/l	<0.1	<0.1	<0.1	<0.1	0.11	0.12	2.1
DiBenxo(a,h)Anthracene	µg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<2.0
benzo(g,h,i)Perylene	µg/l	<0.1	<0.1	<0.1	0.12	0.16	0.24	1.5
Indeno(1,2,3-cd)Pyrene	µg/l	<0.1	<0.1	<0.1	<0.1	0.13	0.27	2.1
Aroclor-1016	µg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
(replicate)								
Aroclor-1221	µg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
(replicate)								
Aroclor-1232	µg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
(replicate)								
Aroclor-1242	µg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
(replicate)								
Aroclor-1248	µg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
(replicate)								
Aroclor-1254	µg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
(replicate)								
Aroclor-1260	µg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
(replicate)								
Microtox 5-min	EC ₅₀	0.18	0.21	0.30	0.16	0.125	0.195	
(replicate)		0.18	0.10	0.295	0.125			
(replicate)								

Table 12. Results of sediment grabs for 24 Oct 91.

Analyte	Units	Site 7	Street Sweeper	Site 12	Site 18	Grain Size Description
Grain Size (%)						
>3/4	inches	0		0		Coarse
>3/8	inches	5		5		Fine
>#4 sieve	(4.8mm)	10		12		Gravel
>#10 sieve	(2.0mm)	15	0	23		Sand
>#20 sieve	(0.84mm)	23	17	32	0	Coarse
>#40 sieve	(0.41mm)	35	36	47	1	Medium
>#60 sieve	(0.23mm)	54	48	61	22	Medium
>#100 sieve	(0.13mm)	71	54	75	41	Fine
>#200 sieve	(0.074mm)	80	60	85	59	Fine
>0.034	mm	83	84	85	83	Silt/Clay
>0.022	mm	86	88	88	86	
>0.012	mm	88	89	90	88	
>0.0092	mm	90	91	91	89	
>0.0067	mm	92	93	92	91	
>0.0048	mm	94	94	94	93	
>0.0031	mm	95	95	95	95	
>0.0012	mm	96	95	96	95	
Aroclor-1016	mg/kg	<1.3	<0.25	<0.025	<0.025	
Aroclor-1221	mg/kg	<1.3	<0.25	<0.025	<0.025	
Aroclor-1232	mg/kg	<1.3	<0.25	<0.025	<0.025	
Aroclor-1242	mg/kg	<1.3	<0.25	<0.025	<0.025	
Aroclor-1248	mg/kg	<1.3	<0.25	<0.025	<0.025	
Aroclor-1254	mg/kg	<1.3	0.27	0.042	<0.025	
Aroclor-1260	mg/kg	6.1	0.40	<0.025	<0.025	
Naphthalene	mg/kg	<0.083	<0.083	<0.83	<17	
Acenaphthylene	mg/kg	<0.17	<0.17	<1.7	<34	
Acenaphthene	mg/kg	<0.17	<0.17	<1.7	<34	
Fluorene	mg/kg	<0.017	0.12	0.055	18	
Phenanthrene	mg/kg	0.099	1.1	0.96	170	
Anthracene	mg/kg	0.031	0.22	0.28	36	
Fluoranthene	mg/kg	0.44	1.9	4.4	340	
Pyrene	mg/kg	0.41	1.1	2.7	200	
Benzo(a)Anthracene	mg/kg	0.12	0.23	0.45	47	
Chrysene	mg/kg	0.26	0.65	1.6	71	
Benzo(b)Fluoranthene	mg/kg	0.41	0.29	0.74	30	
Benzo(k)Fluoranthene	mg/kg	0.10	0.16	0.38	16	
Benzo(a)Pyrene	mg/kg	0.15	<0.017	0.29	16	
DiBenzo(a,h)-Anthracene	mg/kg	<0.034	<0.034	<0.34	6.8	
Benzo(g,h,i)Perylene	mg/kg	0.12	0.18	<0.17	66	
Indeno(1,2,3-cd)-Pyrene	mg/kg	0.035	<0.017	<0.17	9.5	
Arsenic	mg/kg	6.9	23.8	5.8	21.2	
Cadmium	mg/kg	5.1	3.8	2.3	13.9	
Chromium	mg/kg	36.2	33.4	60.6	80.5	
Copper	mg/kg	882	324	2250	276	
Mercury	mg/kg	<0.25	<0.25	0.80	<0.25	
Nickel	mg/kg	35.3	22.7	18.2	56	
Lead	mg/kg	280	196	454.0	583	
Zinc	mg/kg	1060	850	2480.0	1540	
Oil & Grease	mg/kg	16000	59000	2400.0	900	
Total Petro Hydro	mg/kg	3200	4700	1600.0	690	
Total Organic Carbon	mg/kg	16100	26100	15900.0	36500	
Total Organic Halides	mg/kg	170	184	165.0	15	

DISCUSSION

VARIABILITY

The data from this project show much higher variability than seen in most published runoff data. Most other data sets are derived from samples that integrate much larger water sheds. While episodic small-scale events can markedly alter runoff characteristics in the fine-scale sampling of this project, these local fluctuations would be diluted when a single outlet from a large watershed is sampled.

Climatic factors also contribute to the large variability in the data from this study. This study began 4 years into a major drought that lasted throughout the study. Long dry intervals preceding a rain accommodate a large build-up of contaminants. The current study included the first flush following an extended dry spell, as well as in the middle of the rainy season. Thus, both the sampling design and climatic factors contribute to the observed variability. The rain record preceding each storm is listed in appendix D.

Perspective on the magnitude of the variability may be gained by comparison of the results from this study with those of the nationwide urban runoff program (NURP) (EPA, 1983). Most of the sampling stations in the NURP study were in less arid regions. Thus the average variability due to extended dry periods is less. Table 13 shows NURP results for three metals for easy comparison to figure 3 data from this study. As anticipated, the variation in the NURP data is less than in the current study. Appendix E contains an expanded data set from the NURP program for a more detailed comparison of results.

Table 13. Data from the nationwide urban runoff program (NURP)
for three high interest metals.

Concentrations in $\mu\text{g/l}$

NURP Site*	Copper			Lead			Zinc		
	Mean	Median	90% Conf.	Mean	Median	90% Conf.	Mean	Median	90% Conf.
II	36	32	21-48	116	92	66-129	244	225	167-303
III	36	35	28-44	--	--	--	2721	791	217-2882
IV	25	21	14-32	115	92	66-128	223	196	135-284

*NURP Site II, 63 acres, 100 percent industrial, chemical data based on 18 observations.
Site III, 72 acres, 56 percent industrial, chemical data based on 16 observations.
Site IV, 75 acres, 52 percent industrial, chemical data based on 17 observations.

Quality assurance of the analytical procedures indicates that the variability due to analytical technique is quite small relative to the total variability seen. Thus the highly variable chemical and toxicity results are real environmental phenomena.

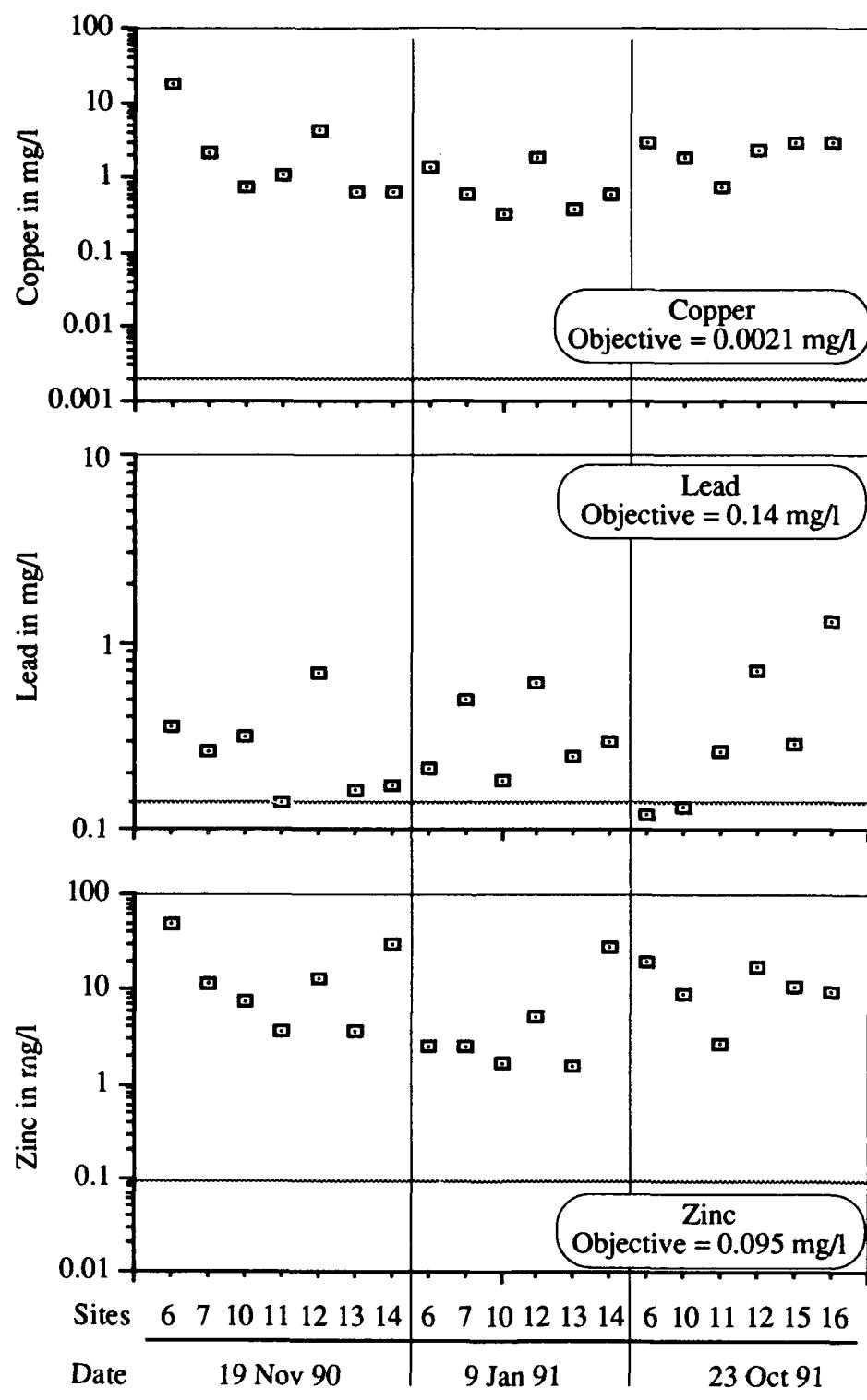


Figure 3. First-flush results for three metals.

*Note: Water quality objectives are 1-hour average for the protection of salt water aquatic life for California.

MAGNITUDE

Relative to NURP

In addition to the high variability seen in this study, contaminant concentrations at times are much higher than typically found in the NURP study. This higher concentration is partly due to the sampling design consisting of fine-scale sampling that resulted in some very near-source samples. Because there is no centralized conveyance for mixing prior to release to the environment, localized chemical contamination results in localized release of contaminants at elevated levels. The storm-drain system creates the potential for localized environmental impacts, and also dictates the appropriateness of the sampling approach taken in this study.

Relative to Water-Quality Objectives

Comparison of contaminant levels between this study and the NURP indicates that the NAVSTA is relatively contaminated for at least several chemicals. In addition to this relative comparison of this industrial facility to others, of premier interest from a regulatory perspective is a determination of whether or not the runoff is contributing to violations of water-quality objectives. Appendix F lists some of the water-quality objectives for bays and estuaries in California. Any runoff with significant contaminant concentrations in excess of these values can be determined to be contributing to violations of objectives and therefore subject to regulatory clean-up requirements.

Comparison of contaminant concentrations with water-quality objectives can provide an initial basis for an ecological risk assessment. Water-quality objectives can provide a synthesis of toxicological data tempered by a recognition of achievable levels given socioeconomic factors. For many chemicals, animal effects are observed at concentrations less than the water-quality objectives; however, from the regulated point-of-view, the objectives will form a major part of the threshold definition by regulatory bodies, and therefore are of particular interest for the Navy.

This report is, however, intended to illustrate approaches to assessment rather than include a comprehensive comparison of measured contaminant levels to water-quality objectives. Selection of several contaminants for comparison will illustrate the process, and is sufficient to indicate a potential for concern.

Three metals were repeatedly measured at levels in excess of water-quality objectives. Those metals are copper, lead, and zinc. Figure 3 shows a selection of contaminant levels for first-flush samples relative to the water-quality objectives. We see from this figure that numerous samples from around NAVSTA from a variety of storms are significantly higher than stated water-quality objectives. Note, concentrations measured by the primary analytical lab are used. An average of replicate values, if available, was also used.

A comparison of the sampling events indicates that the runoff from NAVSTA is at or above the high end of the range for the NURP industrial sites. For the most contaminated sampling (third storm) the runoff is well above the high end of the NURP data, often by several orders of magnitude. This cursory comparison of NAVSTA runoff data with the applicable water-quality objectives indicates that the runoff is sufficiently contaminated to warrant concern of being culpable of water-quality objective violations.

Water-quality objectives are a convenient initial screening approach to identify potential for ecologically significant degradation. Contamination well above objectives should trigger efforts towards load reductions. Conversely, contamination well below these objectives can indicate little need for concern. Only under questionable impact potential is the additional expense of more extensive monitoring and risk assessment warranted.

The previous comparisons of copper and zinc showed levels well above objectives. Lead was at and slightly above objectives. Objectives are not available for petroleum hydrocarbons, but since the runoff was often saturated with petroleum, we presume that petroleum components also are of ecological concern.

NUTRIENTS

Nutrients were measured, not because nutrients are the chemicals of concern at an industrial Navy base or in the receiving water, but because many end-of-the-pipe management techniques are based on biological processes. If the runoff was deficient in nutrients, biological processes could be retarded, resulting in minimal effectiveness.

PARTICULATE BINDING

The filtering technique has a significant impact on the interpretation and application of the filtered sample data. If the samples are filtered as they are withdrawn from the runoff flow a most representative filtered-to-unfiltered ratio results. If the sample sits for some time prior to filtering, chemicals with slow solubility kinetics and particulate interactions would give different results than immediately filtered samples. Many treatment methods involve a settling basin for particulates to settle, co-transporting many of the contaminants. In this type of system, the water and settled particulates have many hours or days in which to come to equilibrium. The samples for the current research were collected and stored prior to filtering. The filtered versus unfiltered data were produced with the intent of use to determine the utility of settling-basin-based technology for treatment. Filtering during collection would be impractical under the field conditions. Normal preservation for many of the analytes requires the addition of acid, but since this would digest the contaminants from the particulate into the

dissolved phase, acid addition was delayed in the to-be-filtered samples until after filtering.

Table 14 shows the solubility tendency of some of the contaminants. Since a number of data points used in the comparisons between filtered and whole effluent samples contained "less than" concentrations, a rigorous statistical comparison is not possible but the general tendency for the nine contaminants listed in table 14 is apparent. Contaminants from the watershed have generally had sufficient time to interact with particulates in their environment. The chemical complexity of the effluent causes solubilities that differ from that predicted by solubility constants based on pure water. Standard solubility characteristics are inadequate for the prediction of the dissolved-to-particulate ratios for contaminants (information valuable for the feasibility analysis of management practices). The implications of particulate binding of contaminants in designing management practices are further addressed in Gadbois (1989, 1990). Solubility tendency changed depending on the total chemical concentration (indicated as "high" and "low" in the table). Therefore, management practices that target either dissolved or particulate phase contaminants may be more or less effective depending on the level of contamination.

Tracking these same three metals as an example, lead demonstrated the strongest tendency to be in the particulate phase. Copper was less so and zinc even less. Preliminary ecological risk evaluation depends on knowledge of partitioning into dissolved and particulate phases. Contaminants in the particulate phase are much less bioavailable to many aquatic organisms. Provided the solubility tendency doesn't change as the runoff mixes with the saline bay water, the presence of these contaminants in the runoff may not be as alarming as otherwise believed when compared to the water-quality objectives. Particulates laden with the nondissolved contaminants tend to settle out of the water column near the outfalls. The particulate adhesion tendencies reduce concern over the contaminants from the perspective of exceeding water-quality objectives, but this is at the expense of contributing to sediment contamination. Sediment contamination adjacent to outfalls is frequently seen so this is a genuine concern.

Table 14. Particulate/dissolved partitioning.

Toxicant Concentration	Toxicant Partitioning							
	Particulate				Dissolved			
Low	Pb	Cr	Ni	Cu	Zn	OP	TKN	Cd
High	Pb	TPH	Cr	Cu	Zn	TKN	Ni	Cd

Settling velocity of particles is a primary consideration in settling basin design. Table 15 indicates that the larger fractions settle rapidly, but the small fraction is very slow to settle. Small particles have higher surface-to-volume ratios than larger particles.

Surface sorption processes occur on a greater per weight basis with small particles. Also for very small particles such as clay, the crystal lattice of the component minerals is large enough relative to the whole particle that the charge balances in the crystal result in an irregularly charged particle surface. Dissolved metals as charged ions have a particular attraction to these small particles. The conclusion is that management that targets particulate bound contaminants (especially metals) should target the hardest-to-retain small particles.

Table 15. Particulate settling velocity in urban runoff.

Driscoll (1983) reported settling velocities of particles in urban runoff as follows:

Proportion %	Average Settling Velocity (ft/hr)
20	0.03
20	0.3
20	1.5
20	7.0
20	65

FROM WATER-QUALITY OBJECTIVES TO DISCHARGE REGULATIONS

Water-quality objectives were used as an indicator that measures the potential for ecological impact from runoff. As a regulated entity, the Navy will primarily experience water-quality objectives indirectly, as they form the basis for the generation of discharge limitations under the NPDES program. Limitations for runoff from industrial facilities in general do not exist yet; but, the monitoring initiated in 40CFR122-124 will likely lead to discharge limits. To the extent that one existing limitation may predict future runoff limitations, table 16 is included as an example.

Table 16. Runoff pollutant limitations for petroleum refining
(From 40CFR419 1 July 1989)

Parameter	Contaminated Runoff	
	1-day maximum	30-consecutive-day maximum
BOD ₅	48	26
Cr (Total)	0.73	0.43
Cr ₆	0.062	0.028
COD	360	180
Oil & Grease	15	8
pH	6.0 – 9.0	6.0 – 9.0
Phenolic compounds	0.35	0.17
TOC	110	--
TSS	33	21

Note: Concentrations are in mg/l. Samples may be single grabs or composites.
Note: Appendix C provides a glossary of abbreviations.

For the contaminants in table 16 that were also measured (Cr, COD, oil and grease, TOC, and TSS) if first-flush samples were used as a 1-day maximum, NAVSTA generally would have been in compliance with these requirements with the exception of total suspended solids.

TOXICITY

The chemical complexity of runoff requires a comparably complex array of analytics for a reasonably complete effluent characterization. These analytics would include a battery of biological and chemical tests. However, a reconnaissance survey of this current study provides basis to determine if there is cause for concern for ecological impact warranting remedial action or more detailed study. This study used a single bioassay technique (microtox) and a small set of chemical analysis. In addition, only first- and late-flush measurements were made. Thus, this reconnaissance monitoring effort cannot be interpreted as a detailed runoff study, but it is sufficient to draw a number of conclusions about the runoff from NAVSTA.

The runoff was contaminated with many chemicals. This contamination not only compounds the complexity for a monitoring program, but in addition poses a synergistic toxicity risk to recipient biota. The biomonitoring data are sufficient to show that the measured toxicity did not correlate well with any particular measured contaminant. Therefore, the toxicity was probably due to the combined effects of multiple toxicants.

Exposure Assessment

The runoff from NAVSTA is freshwater entering San Diego Bay filled with water of near-oceanic salinity. Thus the density of the runoff is less than the receiving water and persists as a floating lens for considerable distances (Chadwick, personal communication). Exposure of resident biota to the contaminants is a complex scenario under these conditions. Near-surface and intertidal biota may be exposed to full-strength runoff with possible salinity and temperature shock in addition to chemical induced effects. Biota living in the saline water underlying the floating lens may receive little exposure due to separation of the water masses. Alternatively, some of the contaminants in the runoff are concentrated in the particulate phase and may be transported downward with the particulate loading that falls through the salinity interface. A different situation may occur when highly turbid (with elevated density) runoff enters a lake or stream. In this case a submerged plume may result. The delay in mixture complicates the determination of environmental impact, and may invalidate the justification for mixing zones in establishing acceptable discharge limits.

The interval between storms influenced the contaminant concentrations. The longer time for accumulation clearly plays a role. The photic-aerobic ground surface where most of the chemicals are deposited prior to their transport in runoff is an

environment rich with pathways for degradation. Recipient biota are subject to a slurry of not only the original contaminants but their degradation products.

MANAGEMENT ALTERNATIVES

This project and report's objective was primarily developing monitoring methods and interpreting data for ecological risk assessment, but in the process information was collected that may assist future management efforts. This section is included to assist runoff managers, but must be followed with caution because it represents an extrapolation from this report's data, the author's visual observations, and untested ideas.

The tidally driven immersion and back flushing of the storm drain system makes end-of-the-pipe approaches impractical at NAVSTA. The decentralized drain system lends itself to decentralized management measures.

Source reduction should be the first step in the management process. Materials substitution or operations changes that use less or nonhazardous materials should be pursued. The Navy has large programs in this area and further discussions are not necessary except to emphasize the value of pursuing that management measure.

Biohazardous materials that are used should be isolated from contact with rain/runoff as much as possible. Confinement, however, must not result in unsafe exposure to NAVSTA personnel.

After implementing appropriate material reductions and handling practices, a large amount of unavoidable sources for contamination of runoff will persist. Clean-up efforts may try to remove contaminants before rain storms, or the contaminated runoff itself may be intercepted and "scrubbed." NAVSTA currently does street sweeping, one method of prerunoff chemical removal. The fifth survey included a single sediment grab sample of material from a repository bin from street sweeping. Chemical analysis (table 12) showed high levels of many of the contaminants found elsewhere around NAVSTA. The street sweeping is therefore effectively removing contaminants that could otherwise end up in the runoff. In addition to runoff improvements, street sweeping removes contaminants from areas used by NAVSTA personnel, thereby improving worker health and safety conditions. Street-sweeping vehicles often spray a mist of water to reduce dust. It would be worth trying the addition of surfactants to the water mist to better extract contaminants clinging to the surface.

Another approach could be to catch the first pulse of runoff and provide some type of treatment. As already mentioned, an end-of-the-pipe retainer would be impractical. One practical approach, appropriate to the decentralized storm-drain system, would be to intercept the water prior to entering the storm drain. Figure 4 illustrates an untested idea for a first-flush retainer. Any number of these retainers could be installed, and most economically in conjunction with other construction projects.

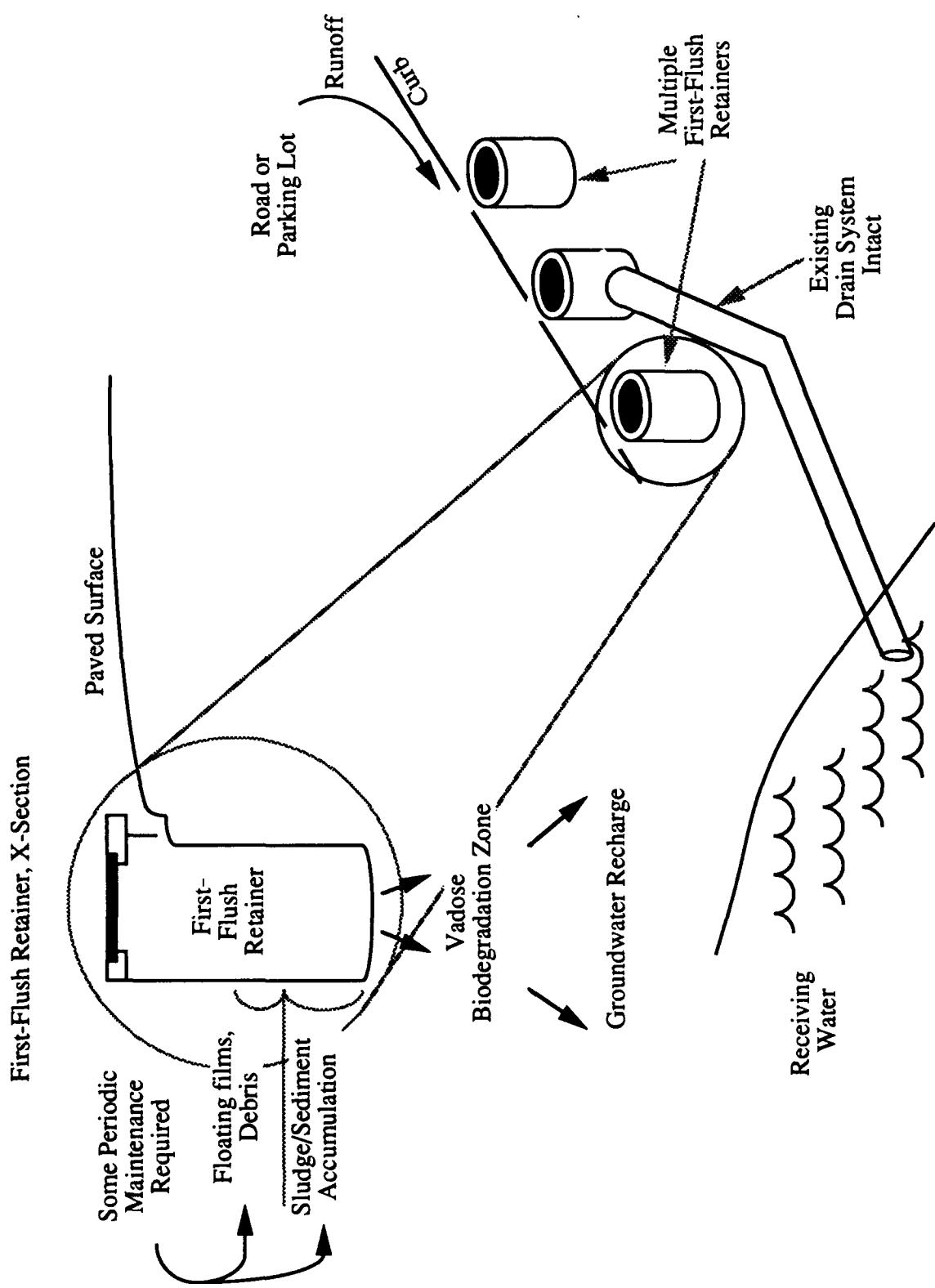


Figure 4. First-flush retainer: a management alternative.

The first-flush retainer in figure 4 in its simplest form is a dead-end manhole with a dirt bottom and an inlet at the curb. These could be located adjacent to storm gratings (inlets to the storm-drain system) or any other convenient locations. When runoff begins to flow towards the grating, it first encounters the opening to the first-flush retainer. Water is diverted and flows into the first-flush retainer until it is full. Once the retainer is full with the water-level flush with the road surface, any additional water will proceed to flow on towards the storm grating. If an additional first-flush retainer is encountered, the process is repeated, thereby capturing a larger first flush. Any additional runoff flows on down the storm drain as it does currently. The dirtiest runoff, now contained in the first-flush retainer, slowly infiltrates into the soil beneath. Within perhaps several days the chamber has drained and is ready to intercept the next first flush. If a second rain storm occurs before the chamber has drained, only a small portion of the first flush from the second storm would be retained. This second storm however is not an environmental concern because the first flush will probably be quite clean since so little time has passed since the last storm to allow accumulation of contaminants on the ground surface.

After extended use, the first-flush retainer will begin to fill with sediment and debris, so a periodic cleaning will be needed to maintain its capacity. Many contaminants will accumulate in this material that is periodically removed. In addition, a resident microbial colony will probably develop to metabolize some of the contaminants. There is however some risk to groundwater contamination in this and any management practice based on infiltration.

A variation would be the insertion of material into the first-flush retainer that is particularly sorptive of the contaminants. As an example, many organic and metal contaminants have a high sorptive affinity for organic material. A plug of organic material such as moss or peat is an example.

In addition to the first-flush retainer, the reader is alerted to many management plans outlined in three noteworthy references: U.S. EPA, 1983; Scheuler, 1987; and U.S. EPA, 1991.

CONCLUSIONS

Contaminant levels in runoff from this industrial facility warrant the implementation of management measures. The data collected preceded any regulatory requirements for monitoring. This affords the Navy the opportunity to continue taking a proactive stance to recognize opportunities to implement management programs suited to its facility design and operational requirements.

Management at an existing facility such as NAVSTA will involve a multifaceted approach. Best management practices can immediately influence loading rates. The

facility lay-out and topography preclude application of a centralized treatment system but a distributed treatment system is feasible and is probably a cost-effective approach.

First-flush runoff is more contaminated and toxic than much later in a storm. The greatest reductions in total loadings and acute toxicity will be achieved if management measures target the first flush. Once the first flush is retained or treated, additional monitoring will identify if the remaining contaminant flux poses significant ecological risk to warrant additional management expenses.

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APPENDIX A

CALCULATION OF RUNOFF COEFFICIENTS

A runoff coefficient is the ratio of the incident precipitation to the amount that flows off as runoff. This coefficient is rather easily measured empirically using a rain gauge and flow meter. This has been done repeatedly by others and a sampling of their results is included. A primary controlling parameter of the amount of rain that leaves a site as runoff is the permeability of the surface. The permeability is drastically affected by surface conditions such as buildings, pavement, vegetation, etc. Table A-1 shows a sample of empirical examples, and following the table are equations to estimate the runoff coefficient.

Table A-1. Empirical results of runoff coefficients.

Researcher	Site Description	Mean Runoff Coefficient
Kobriger et al. (1982)	100% paved	0.83
	51% paved	0.71
	27 % paved	0.43
Mar et al. (1982)	100% paved	0.72 - 0.80
Viessman(1977) cited in Marsalak & Schroeter (1988)	Residential	0.35
	Commercial	0.90
	Industrial	0.70
	Open land	0.10

Mar et al. (1982) recommended use of equation 1, developed at the U.S. Army Corps of Engineers' Hydrologic Engineering Center to use with partially paved drainage areas:

$$C = C_p + (C_i + C_p)X \quad (1)$$

where:

C = Runoff coefficient or the ratio of total runoff to total rainfall.

C_p = Runoff coefficient for pervious areas (default value = 0.45).

C_i = Runoff coefficient for impervious areas.

X = Impervious area/total area.

Runoff volume can then be estimated by equation 2:

$$V_R = (C)(R_V)(A_D) \quad (2)$$

where:

- V_R = Runoff volume.
- C = Runoff coefficient.
- R_V = Rainfall depth.
- A_D = Drainage area.

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APPENDIX B

LOCATION AND DRAINAGE BASIN DESCRIPTION BY SITE

Site	Description
1	N.W. corner of Brinser and Wooden—by fire hydrant. This water flows to the grating in the middle of Brinser straight south of this site.
2	Roadside pooled runoff on the opposite side of Brinser Street.
2A	One-hundred percent paved with buildings. Includes automobile parking and roadway; combustion and chemical foam fallout from fire-fighting training. Storm grating across Brinset Street from the fence gate into the FTC fire school, near building 217.
3	One-hundred percent paved or concrete with gasoline pumps used for auto refueling.
4	Paved road with auto and heavy equipment traffic, and an electrical transformer relay station, and packed-dirt equipment storage.
5	Equipment refurbishing including paints, solvents, heavy equipment, some chemical storage. Long-term auto storage on dirt lot. Site 5 contributes to site 6.
6	This site is sheet flow over the quaywall at the north corner of the basin formed by mole pier and pier 10. An expansive paved region with paint and accessories storage, paved roadway with extensive heavy equipment traffic and use, dirt parking lots, dirt and paved equipment and vehicle parking.
7	One-hundred percent paved with several small buildings. Moderate traffic roadways, auto parking, adjacent to a ship drydock.
8	Storm grating at the south corner of the intersection of Buchanan and Sturtevant.
9	About 100 feet SW on 7th Street from the intersection of 7th and Cummings. Grating was on the NW side of 7th Street, on the shoulder towards Paleta creek.
10	Storm grating at the south corner of building 20. There are two nearly adjacent gratings; site 10 was the more southeasterly of the two. Area is 100 percent paved with buildings. Extensive auto parking, auto and equipment traffic.
11	Storm grating at the south corner of the intersection of 12th and Kidd Street. Small amount of paved roads with mild traffic. Otherwise dirt used for vehicle parking, small boat hull cleaning/painting.
12	One-hundred percent paved with buildings. Includes extensive auto parking, little vehicle traffic, solvent cleaning baths for machinery, light and heavy equipment use. Tugboat shoreside facilities.
13	Paved roadways, outdoor metal works, heavily used auto parking lot surfaced with crushed rock.
14	One-hundred percent paved with buildings. Light vehicle traffic and parking. Wash-down of metal working area. Nonfuel vehicle fluids storage and use.
15	One-hundred percent paved with buildings, parking.
16	Primarily paved, not directly down gradient, but several hundred feet from a hazardous material staging area.
18	Down gradient from numerous creosote-soaked logs to be used as pilings. Not directly down gradient, but several hundred feet from a hazardous material staging area.

APPENDIX C

GLOSSARY OF ABBREVIATIONS

ANALYSIS

BHC	Hexachlorocyclohexane (old name - benzene hexachloride)
Cr+6	Hexavalent Chromium (a particularly toxic form)
COD	Chemical oxygen demand
EC ₅₀	Runoff to blank ratio that produces a 50% reduction in light output
PAHs	Polynuclear Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
TOC	Total Organic Carbon
TKN	Total Kjeldahl Nitrogen
TPH	Total Petroleum Hydrocarbons
Total Petrol Hydro	Total Petroleum Hydrocarbons
TSS	Total suspended solids

TECHNIQUE

AA/Cold Vapor	Atomic Absorption / Cold Vapor
AA/GF	Atomic Absorption / Graphite Furnace
ASTM	American Society for Testing and Materials
IR	Infrared Spectrometer
ICAP	Inductively Coupled Argon Plasma
GC/ECD	Gas Chromatography/Electron Capture Detector
GC/MS	Gas Chromatography/Mass Spectroscopy
HPLC	High Performance Liquid Chromatography
SMEWW	Standard Methods for the Examination of Water and Wastes
TOX	Total Organic Halides

APPENDIX D

RAINFALL DATA

**From the NOAA National Weather Service
Lindberg Field (San Diego Airport) and National City**

The weather observation post in National City (nearest to NAVSTA) is less reliable in reporting daily rainfall totals than is the dependable main NOAA weather station at Lindberg Field. Therefore 24-hour data (as of 4:00 PM) are included for National City as available, and make up the far-right column in the table. The remainder of the data is for Lindberg Field.

Lindberg (San Diego) Airport					
4:00 PM on Date	Past 24 hrs	Month Total	Storm Total	Season Total	National City (24 hrs)
25 Nov 89	T	T	T	0.70	T
26 Nov 89	0.09	0.09	0.09	0.79	n/a
28 Dec 89	T	T	T	0.79	T
29 Dec 89	1.01	1.01	1.01	1.80	0.54
30 Dec 89	0.0	1.01	0.0	1.80	0.0
1 Jan 90	0.0	0.0	0.0	1.80	0.0
2 Jan 90	0.43	0.43	0.43	2.23	0.29
3 Jan 90	T	0.43	0.43	2.23	0.0
12 Jan 90	0.0	0.43	0.0	2.23	0.0
13 Jan 90	0.11	0.54	0.11	2.34	0.11
14 Jan 90	0.92	1.35	0.92	3.15	0.49
15 Jan 90	0.20	1.54	1.12	3.35	0.22
16 Jan 90	0.07	1.62	1.19	3.42	0.18
17 Jan 90	0.54	2.16	1.73	3.96	0.58
18 Jan 90	0.02	2.16*	1.73*	3.96*	0.0
19 Jan 90	0.0	2.16	0.0	3.96	0.0
30 Jan 90	0.0	2.16	0.0	3.96	0.0
31 Jan 90	0.36	2.52	0.36	4.32	0.46
1 Feb 90	T	T	T	4.32	0.0
8 June 90	0.0	0.0	0.0	6.97	0.0
9 June 90	0.38	0.38	0.38	7.35	0.16
10 June 90	0.49	0.87	0.87	7.84	0.42
11 June 90	T	0.87	0.87	7.84	T
13 June 90	T	0.87	T	7.84	0.0
29 June 90	T	0.87	T	7.84	0.0
30 June 90	0.87	0.0	7.84	0.0	
1 July 90	0.0	0.0	0.0	0.0	0.0
12 July 90	0.0	0.0	0.0	0.0	0.0
13 July 90	T	T	T	T	0.0

*Note the slight error in cumulative rainfall beginning 18 Jan 90 is in the National Weather Service records.
"T" indicates a trace.

Lindberg (San Diego) Airport (continued)

4:00 PM on Date	Past 24 hrs	Month Total	Storm Total	Season Total	National City (24 hrs)
13 Aug 90	0.0	T	0.0	T	0.0
14 Aug 90	0.01	0.01	0.01	0.01	T
13 Sept 90	T	T	T	0.01	n/a
1 Oct 90	T	T	T	0.01	0.0
31 Oct 90	0.0	T	0.0	0.01	0.0
1 Nov 90	0.02	0.02	0.02	0.03	0.03
2 Nov 90	0.0	0.02	0.0	0.03	0.0
19 Nov 90	0.0	0.02	0.0	0.03	0.0
20 Nov 90	0.53	0.55	0.53	0.56	0.48
21 Nov 90	0.0	0.55	0.0	0.56	0.0
26 Nov 90	0.10	0.65	0.10	0.66	0.0
12 Dec 90	T	T	T	0.66	T
16 Dec 90	T	T	T	0.66	0.02
19 Dec 90	0.06	0.06	0.06	0.72	0.03
20 Dec 90	0.45	0.51	0.51	1.17	0.22
21 Dec 90	0.07	0.58	0.58	1.24	0.13
22 Dec 90	0.01	0.59	0.59	1.25	T
29 Dec 90	T	0.59	T	1.25	T
2 Jan 91	0.0	0.0	0.0	1.25	0.0
3 Jan 91	0.09	0.09	0.09	1.34	0.09
4 Jan 91	0.70	0.79	0.79	2.04	0.52
5 Jan 91	0.0	0.79	0.0	2.04	T
8 Jan 91	0.0	0.79	0.0	2.04	0.0
9 Jan 91	0.27	1.06	0.27	2.31	0.28
10 Jan 91	0.0	1.06	0.0	2.31	0.0
30 July 91	0.0	0.01	0.0	0.01	0.0
31 July 91	0.23	0.24	0.23	0.24	0.42
1 Aug 91	0.01	0.01	0.01	0.25	0.0
11 Aug 91	T	0.01	T	0.25	0.0
12 Aug 91	T	0.01	T	0.25	T
14 Aug 91	T	0.01	T	0.25	T
16 Aug 91	T	0.01	T	0.25	0.0
5 Sept 91	T	T	T	0.25	0.0
6 Sept 91	0.04	0.04	0.04	0.29	0.01
13 Sept 91	T	0.04	T	0.29	T
14 Sept 91	T	0.04	T	0.29	0.0
20 Sept 91	T	0.04	T	0.29	T
21 Sept 91	0.24	0.28	0.24	0.53	0.05
15 Oct 91	T	T	T	0.53	0.0
16 Oct 91	T	T	T	0.53	0.0
23 Oct 91	0.0	T	0.0	0.53	T
24 Oct 91	0.19	0.19	0.19	0.72	0.22

APPENDIX E

NATIONWIDE URBAN RUNOFF PROGRAM (NURP) DATA

This appendix contains selected data from the Nationwide Urban Runoff Program (NURP), provided in a synthesized form for easier comparison with the data produced in the current study. Tables E-1 through E-5 contain NURP metals data for the three metals that were consistently above water-quality objectives in the current study. Tables E-6 through E-10 contain nutrient and suspended solids data. Both industrial and nonindustrial results are presented to illustrate how the industrial runoff measured in the current study might compare with runoff from less and nonindustrial areas. This industrial versus nonindustrial comparison is more succinctly illustrated in figure E-1.

REFERENCE

EPA. 1983. "Results of the Nationwide Urban Runoff Program: Volume 1—Final Report." U.S. Environmental Protection Agency, Water Planning Division, Washington, D.C.

Table E-1. Copper, lead, zinc in industrial park runoff (nationwide) from EPA 1983.

Site	State	% Ind.	Area (A)	Pop #/A	% Imp.	Copper			Lead			Zinc		
						# Obs	Mean	Median	90% Limits	# Obs	Mean	Median	90% Limits	# Obs
1 MI	100	63	0	64	6	0.036	0.032	0.021-0.048	13	0.116	0.092	0.066-0.129	7	0.244
2 KS	56	72	—	44	5	0.036	0.035	0.028-0.044	—	—	—	0.066-0.128	6	2.721
3 MI	52	75	5	39	7	0.025	0.021	0.014-0.032	13	0.115	0.092	0.066-0.128	7	0.196
													0.167-0.303	0.217-2.882
													0.135-0.284	

Table E-2. Copper, lead, zinc in commercial runoff (nationwide) from EPA 1983.

Site	State	% Com.	Area (A)	Pop #/A	% Imp.	Copper			Lead			Zinc		
						# Obs	Mean	Median	90% Limits	# Obs	Mean	Median	90% Limits	# Obs
1 CO	100	74	0	91	27	0.033	0.025	0.020-0.032	27	0.262	0.167	0.122-0.228	27	0.320
2 NC	100	23	0	69	61	0.070	0.061	0.055-0.068	61	0.382	0.296	0.254-0.345	60	0.533
3 NY	100	179	2	21	0	—	—	—	13	0.047	0.042	0.033-0.053	9	1.416
4 WI	100	12	0	100	0	—	—	—	59	0.193	0.148	0.126-0.173	32	0.145
5 NH	100	1	0	90	31	0.104	0.103	0.098-0.106	33	0.208	0.152	0.121-0.192	33	0.513
6 TN	100	26	0	99	15	0.042	0.036	0.028-0.046	15	0.158	0.140	0.112-0.175	15	0.315
7 WI	100	12	0	—	0	—	—	—	44	0.121	0.098	0.083-0.115	19	0.156
8 KS	96	58	—	97	6	0.041	0.039	0.030-0.051	7	—	—	—	7	0.465
9 FL	91	47	—	45	12	0.011	0.010	0.008-0.013	12	0.046	0.032	0.021-0.049	12	0.037
10 WI	74	29	10	77	0	—	—	—	27	0.409	0.319	0.243-0.396	7	0.280
													0.240-0.349	
													0.096-0.163	
													0.368	
													0.222-0.611	
													0.019-0.041	
													0.150-0.363	

Table E-3. Copper, lead, zinc in urban open and nonurban runoff (nationwide) from EPA 1983.

Site	State	% Open	Area (A)	Pop #/A	% Imp.	Copper			Lead			Zinc		
						# Obs	Mean	Median	90% Limits	# Obs	Mean	Median	90% Limits	# Obs
1 CA	100	633	—	—	12	0.58	0.055	0.046-0.065	7	0.214	0.159	0.091-0.279	17	0.190
2 CO	100	405	0	1	7	0.037	0.025	0.013-0.048	—	0.052	0.039	0.022-0.069	7	0.105
3 NY	100	28,416	—	4	0	—	—	—	10	0.012	0.011	0.009-0.014	9	0.792
4 NY	98	5,248	—	1	0	—	—	—	21	0.009	0.008	0.006-0.010	0	—
5 NY	97	5,338	—	1	0	—	—	—	25	0.038	0.022	0.015-0.031	0	—
6 NY	91	17,728	1	11	0	—	—	—	12	0.035	0.018	0.010-0.033	9	1.063
7 NY	80	552	—	7	0	—	—	—	33	0.132	0.091	0.071-0.117	0	—
													0.124-0.839	
													—	
													0.125-0.205	
													0.061-0.135	
													0.130-0.720	

Table E-4. Copper, lead, zinc in residential runoff (nationwide) from EPA 1983.

Site	State	% Res.	Area (A)	Pop #/A	% Imp.	Copper			Lead			Zinc		
						# Obs	Mean	Median	90% Limits	# Obs	Mean	Median	90% Limits	# Obs
						#	Obs	Mean	Median	#	Obs	Mean	Median	#
1 CO	100	33	19	41	16	0.032	0.025	0.018-0.034	16	0.183	0.137	0.098-0.191	15	0.194
2 CO	100	57	24	38	14	0.035	0.020	0.012-0.033	14	0.194	0.143	0.099-0.207	14	0.195
3 CO	100	167	14	24	16	0.028	0.022	0.016-0.029	16	0.292	0.210	0.151-0.292	16	0.195
4 DC	100	12	—	21	—	—	—	—	1	—	—	—	8	0.156
5 DC	100	68	21	33	14	0.038	0.033	0.026-0.042	19	0.227	0.200	0.164-0.245	48	0.129
6 DC	100	8	—	10	0.028	0.027	0.023-0.032	0	—	—	—	28	0.084	
7 IL	100	54	18	19	36	0.083	0.063	0.051-0.078	36	0.237	0.191	0.158-0.231	0	—
8 KS	100	58	8	38	12	0.091	0.081	0.093-0.103	11	0.138	0.128	0.104-0.157	13	0.831
9 MD	100	14	30	51	19	0.107	0.088	0.068-0.112	19	2.745	0.592	0.295-1.188	19	1.388
10 MD	100	23	9	29	13	0.312	0.296	0.252-0.349	13	0.076	0.069	0.056-0.086	13	0.120
11 MD	100	17	12	29	20	0.026	0.020	0.015-0.026	20	0.086	0.077	0.065-0.092	20	0.092
12 MD	100	10	55	76	13	0.042	0.067	0.025-0.046	13	0.461	0.218	0.119-0.399	13	0.531
13 NY	100	—	—	0	—	—	—	—	8	0.088	0.052	0.026-0.103	0	—
14 NY	100	166	5	22	0	—	—	—	13	0.034	0.027	0.049-0.038	9	0.415
15 NY	100	346	18	38	0	—	—	—	8	0.193	0.144	0.086-0.240	8	0.488
16 WA	100	95	9	29	0	—	—	—	118	0.152	0.136	0.126-0.146	118	0.124
17 WI	100	63	15	50	0	—	—	—	44	0.095	0.077	0.065-0.091	18	0.106
18 WI	100	33	17	51	0	—	—	—	35	0.108	0.090	0.075-0.107	21	0.108
19 FL	100	9	—	6	12	0.006	0.006	0.005-0.007	12	0.076	0.053	0.034-0.082	12	0.060
20 WI	97	36	18	57	0	—	—	—	22	0.303	0.200	0.143-0.280	0	—
21 TN	96	89	4	13	11	0.028	0.015	0.008-0.027	11	0.133	0.123	0.099-0.153	11	0.093
22 DC	93	41	3	21	6	0.037	0.034	0.024-0.048	5	0.186	0.184	0.157-0.216	34	0.067
23 IL	91	39	18	36	0.043	0.033	0.026-0.040	33	0.217	0.169	0.138-0.208	1	—	
24 TN	91	69	11	33	11	0.061	0.062	0.038-0.070	11	0.440	0.376	0.277-0.511	11	0.412
25 WA	91	102	12	37	5	0.022	0.0212	0.015-0.029	126	0.192	0.159	0.146-0.174	126	0.120
26 IL	90	28	22	37	36	0.045	0.036	0.030-0.044	37	0.595	0.396	0.308-0.508	0	—
27 FL	89	42	—	16	12	0.010	0.007	0.005-0.011	12	0.049	0.026	0.014-0.047	12	0.054
28 DC	88	19	—	34	9	0.026	0.025	0.019-0.031	1	—	—	—	44	0.086
29 CO	86	127	9	22	9	0.059	0.045	0.029-0.071	9	0.433	0.351	0.253-0.524	9	0.349
30 IL	85	524	8	17	26	0.049	0.043	0.036-0.051	24	0.322	0.227	0.159-0.304	27	0.230
31 MA	85	154	11	16	6	0.107	0.104	0.086-0.125	6	0.271	0.136-0.371	6	0.247	
32 NC	84	324	6	27	66	0.039	0.033	0.029-0.037	66	0.254	0.182	0.153-0.215	66	0.178
33 MA	79	110	10	21	8	0.074	0.072	—	9	0.168	0.160	0.132-0.194	9	0.218
34 DC	78	27	15	34	11	0.030	0.028	0.023-0.035	11	0.141	0.130	0.105-0.161	45	0.091

Table E-5. Copper, lead, zinc in mixed runoff (nationwide) from EPA 1983.

Site	State	Area (A)	Pop #/A	% Imp.	# Obs	Copper			Lead			Zinc				
						Mean	Median	90% Limits	Obs	Mean	Median	90% Limits	Obs	Mean		
1	KS	36	3	68	9	0.048	0.045	0.036-0.057	9	0.164	0.147	0.110-0.196	9	0.814	0.525	0.293-0.940
2	MD	17	40	72	20	0.081	0.061	0.046-0.082	20	0.227	0.176	0.133-0.232	13	0.318	0.112	0.225-0.340
3	IL	17	3	58	37	0.048	0.037	0.031-0.045	41	0.554	0.380	0.303-0.478	0	—	—	—
4	MI	30	11	68	16	0.015	0.013	0.010-0.016	34	0.111	0.075	0.055-0.102	17	0.121	0.110	0.092-0.132
5	TN	187	3	43	13	0.042	0.025	0.015-0.041	13	0.237	0.227	0.195-0.264	13	0.149	0.138	0.114-0.167
6	WI	45	12	81	0	—	—	—	45	0.582	0.424	0.348-0.517	27	0.476	0.303	0.222-0.414
7	MA	338	7	23	7	0.112	0.100	0.071-0.141	7	0.439	0.307	0.165-0.571	7	0.244	0.225	0.166-0.304
8	MA	100	1	33	7	0.105	0.096	0.071-0.130	7	0.196	0.143	0.080-0.257	7	0.202	0.174	0.116-0.260
9	MI	453	5	38	13	0.030	0.026	0.020-0.068	18	0.122	0.091	0.066-0.125	14	0.245	0.200	0.148-0.271
10	MI	2001	2	21	0	—	—	—	6	0.021	0.011	0.004-0.028	4	—	—	—
11	NY	765	—	5	0	—	—	—	28	0.075	0.047	0.034-0.064	0	—	—	—
12	MA	601	9	12	5	0.054	0.048	0.030-0.076	4	—	—	—	5	0.178	0.099	0.035-0.279
13	MI	2871	7	26	0	—	—	—	5	0.061	0.050	0.027-0.092	4	—	—	—
14	MI	164	5	28	9	0.014	0.013	0.011-0.016	18	0.170	0.099	0.065-0.151	9	0.149	0.140	0.113-0.173
15	SD	2030	—	—	0	—	—	—	24	0.383	0.254	0.165-0.390	0	—	—	—
16	CA	1542	12	—	17	0.098	0.065	0.044-0.096	22	0.495	0.351	0.259-0.475	21	0.303	0.231	0.175-0.305
17	FL	30	—	13	15	0.007	0.006	0.005-0.008	15	0.056	0.035	0.023-0.054	15	0.094	0.078	0.059-0.103
18	FL	194	—	97	15	0.006	0.005	0.004-0.007	15	0.085	0.065	0.046-0.091	15	0.051	0.037	0.026-0.053
19	CO	69	9	50	32	0.077	0.059	0.048-0.074	33	0.358	0.278	0.226-0.343	33	0.543	0.421	0.341-0.520

E-4

Table E-6. TSS, total phosphorus, and TKN in industrial park runoff (nationwide) from EPA 1983.

Site	State	% Res.	Area (A)	Pop #/A	% Imp.	# Obs	TSS			Total Phos.			TKN				
							Mean	Median	90% Limits	Obs	Mean	Median	90% Limits	Obs	Mean		
1	MA	100	18	0	69	5	48	37	19-73	5	0.114	0.085	0.041-0.176	5	2.092	1.879	1.207-2.924
2	MI	100	63	0	64	18	92	71	53-95	18	0.546	0.472	0.378-0.589	18	1.274	1.107	0.891-1.376
3	KS	56	72	—	44	18	102	61	40-92	16	0.599	0.452	0.325-0.628	12	1.385	1.117	0.793-1.568
4	MI	52	75	5	39	20	188	137	101-186	17	0.435	0.355	0.271-0.465	18	1.713	1.493	1.205-1.850

Table E-7. TSS, total phosphorus, and TKN in commercial runoff (nationwide) from EPA 1983.

Site	State	% Res.	Area (A)	Pop #/A	% Imp.	TSS			Total Phos.			TKN					
						# Obs	Mean	Median	# Obs	Mean	Median	90% Limits	90% Limits	90% Limits			
1	CO	100	74	0	91	27	260	122	81-183	0.734	0.438	0.318-0.603	27	3.657	2.785	2.186-3.548	
2	NC	100	23	0	69	60	63	107	88-131	0.395	0.342	0.304-0.383	61	1.613	1.318	1.152-1.509	
3	NY	100	179	2	21	12	141	122	79-159	0.216	0.209	0.183-0.239	12	1.256	1.144	0.925-1.414	
4	WI	100	12	0	100	58	212	161	131-197	0.108	0.094	0.084-0.105	60	1.023	0.936	0.815-1.075	
5	NH	100	1	0	90	32	74	38	27-54	0.273	0.174	0.127-0.238	27	2.112	1.761	1.376-2.254	
6	TN	100	26	0	99	15	123	99	74-133	0.212	0.195	0.162-0.235	15	0.646	0.597	0.499-0.714	
7	WI	100	12	0	—	42	202	167	142-196	0.105	0.082	0.069-0.098	44	25	1.073	0.916	0.755-1.110
8	KS	96	58	—	97	22	80	34	21-55	0.246	0.176	0.128-0.242	20	1.175	0.949	0.720-1.252	
9	FL	91	47	—	45	12	22	14	9-22	0.151	0.135	0.106-0.172	12	0.826	0.633	0.433-0.925	
10	WI	74	29	10	77	29	412	296	229-382	0.330	0.245-0.443	0.245-0.443	29	8	1.656	1.389	0.933-2.068

Table E-8. TSS, total phosphorus, and TKN in urban open and nonurban runoff (nationwide) from EPA 1983.

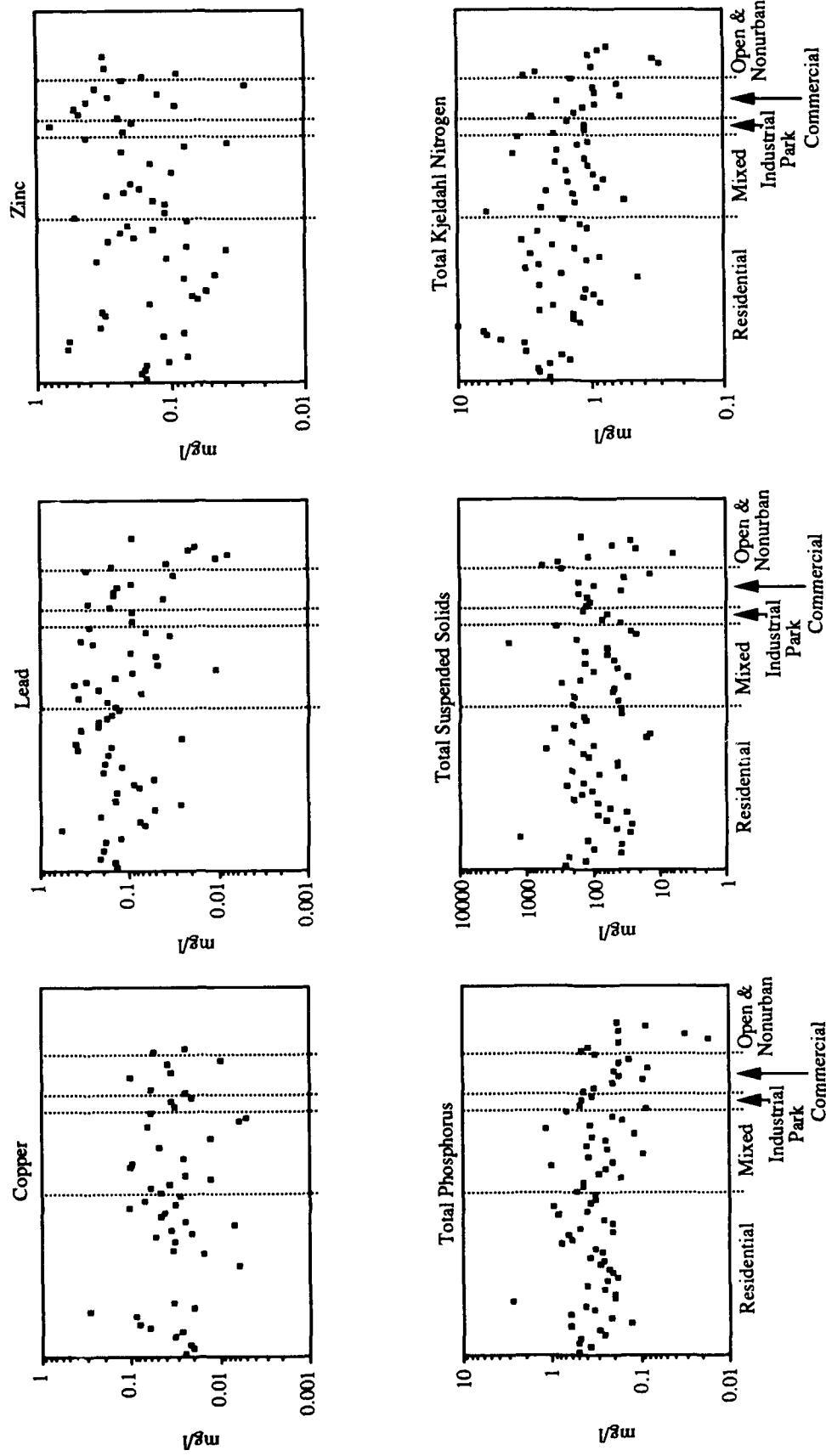
Site	State	% Res.	Area (A)	Pop #/A	% Imp.	TSS			Total Phos.			TKN					
						# Obs	Mean	Median	# Obs	Mean	Median	90% Limits	90% Limits	90% Limits			
1	CA	100	633	—	—	13	718	551	385-788	0.590	0.455	0.319-0.649	13	3.674	3.159	2.411-4.139	
2	CO	100	405	0	1	7	403	341	223-521	0.420	0.380	0.274-0.528	7	2.954	2.615	1.815-3.768	
3	NY	100	28,416	—	4	11	154	113	74-173	0.193	0.175	0.141-0.217	13	1.099	0.982	0.778-1.240	
4	NY	98	5,248	—	1	28	17	6	4-10	0.027	0.017	0.013-0.023	30	15	0.340	0.305	0.246-0.378
5	NY	97	5,338	—	1	28	64	22	14-35	0.052	0.032	0.024-0.043	31	24	0.392	0.347	0.292-0.412
6	NY	91	17,728	1	11	9	63	51	34-77	0.195	0.177	0.140-0.233	12	10	1.111	1.045	8.540-1.279
7	MI	90	2,303	—	5	33	26	14-50	5	0.091	0.085	0.060-0.121	5	5	0.889	0.883	0.796-0.981
8	NY	80	552	—	7	32	378	149	99-224	0.264	0.186	0.145-0.238	33	33	0.963	0.765	0.628-0.932

Table E-9. TSS, total phosphorus, and TKN in residential runoff (nationwide) from EPA 1983.

Site	State	% Res.	Area (A)	Pop #/A	# Imp.	TSS			Total Phos.			TKN					
						# Obs.	Mean	Median	90% Limits		# Obs.	Mean	Median	90% Limits			
									90% Limits	90% Limits				90% Limits	90% Limits		
1	CO	100	33	19	41	16	383	265	182-385	16	0.693	0.505	0.356-0.716	16	2.369	2.041	1.612-2.584
2	CO	100	57	24	38	14	180	129	87-190	13	0.429	0.377	0.297-0.479	14	2.609	2.430	2.034-2.904
3	CO	100	167	14	24	16	365	232	154-349	15	0.630	0.513	0.392-0.672	15	2.893	2.501	2.010-3.112
4	DC	100	12	—	—	8	56	39	51-74	5	0.499	0.475	0.353-0.640	6	2.066	2.048	1.841-2.278
5	DC	100	68	21	33	49	175	98	76-127	48	0.323	0.256	0.217-0.302	48	1.724	1.450	1.259-1.670
6	DC	100	8	—	—	33	54	38	30-49	28	0.340	0.300	0.255-0.353	28	1.811	1.686	1.494-1.904
7	IL	100	54	18	19	51	205	122	96-155	33	0.750	0.636	0.538-0.753	33	3.994	3.107	2.520-3.831
8	KS	100	58	8	38	158	2216	1247	766-2032	8	1.636	0.127	0.717-2.031	5	—	—	—
9	MA	100	50	5	16	5	78	29	8-111	5	0.314	0.216	0.950-0.491	5	3.679	3.217	1.971-5.252
10	MD	100	14	30	51	18	74	45	30-68	19	0.932	0.613	0.425-0.883	18	6.067	4.815	3.640-6.370
11	MD	100	23	9	29	13	50	26	15-46	13	0.421	0.345	0.253-0.471	13	6.505	6.044	4.996-7.312
12	MD	100	17	12	29	20	95	63	44-89	20	0.556	0.428	0.324-0.566	20	6.935	6.408	5.502-7.463
13	MD	100	10	55	76	13	127	88	57-135	13	4.090	2.825	1.845-4.326	13	10.803	9.915	8.089-12.154
14	NY	100	73	13	20	23	42	32	25-42	24	0.221	0.195	0.163-0.233	24	1.487	1.201	0.955-1.509
15	NY	100	—	—	8	65	57	41-80	8	0.229	0.196	0.134-0.285	8	1.408	1.363	1.148-1.618	
16	NY	100	166	5	22	10	134	88	52-150	13	0.301	0.265	0.206-0.340	13	1.492	1.358	1.098-1.679
17	NY	100	346	18	38	7	294	196	101-380	8	0.448	0.405	0.300-0.546	7	3.246	2.411	1.369-4.245
18	TX	100	60	3	21	9	227	150	85-263	9	0.268	0.233	0.169-0.322	9	5.004	1.942	0.825-4.554
19	WA	100	95	9	29	113	113	101	94-108	11	0.239	0.184	0.164-0.205	118	1.007	0.857	0.785-0.935
20	WI	100	63	15	50	45	266	243	219-270	45	0.229	0.209	0.188-0.233	—	1.260	1.125	0.908-1.395
21	WI	100	33	17	51	33	170	141	117-169	35	0.258	0.230	0.201-0.264	18	1.102	1.069	0.801-1.173
22	FL	100	9	—	6	12	53	34	21-56	12	0.333	0.279	0.205-0.380	12	1.339	1.097	0.791-1.522
23	TX	99	378	9	40	15	156	82	48-137	14	0.333	0.260	0.179-0.349	11	3.016	2.412	1.674-3.474
24	WI	97	36	18	57	23	251	206	165-258	23	0.453	0.373	0.298-0.466	1	—	—	—
25	TN	96	89	4	13	11	63	42	25-68	11	0.246	0.227	0.183-0.282	11	0.476	0.452	0.379-0.539
26	DC	93	41	3	21	41	75	43	33-57	41	0.397	0.319	0.268-0.380	41	1.901	1.660	1.447-1.904
27	KS	92	63	—	37	13	156	119	83-171	10	1.297	0.787	0.441-1.405	8	4.187	3.051	1.790-5.205
28	IL	91	39	18	18	49	248	138	106-178	32	0.732	0.604	0.502-0.727	32	3.527	2.441	1.888-3.155
29	TN	91	69	11	33	11	611	492	345-704	11	0.705	0.665	0.522-0.801	11	1.131	1.071	0.894-1.283
30	WA	91	102	12	37	126	127	100	90-110	127	0.264	0.204	0.184-0.227	127	1.056	0.842	0.774-0.938
31	IL	90	28	22	37	59	311	211	174-256	32	0.587	0.483	0.401-0.582	32	3.440	2.825	2.343-3.406
32	FL	89	42	—	16	12	33	16	9-30	12	0.395	0.208	0.116-0.374	12	1.704	1.309	0.899-1.905
33	DC	88	19	—	34	47	25	14	10-18	47	0.351	0.254	0.242-0.334	46	2.212	1.958	1.731-2.215
34	CO	86	127	9	22	9	493	380	244-593	9	1.025	0.834	0.561-1.239	7	3.735	3.263	2.224-4.788
35	IL	85	524	8	17	27	250	200	161-249	26	0.506	0.397	0.314-0.501	0	—	—	—
36	MA	85	154	11	16	6	257	128	48-339	6	1.228	0.966	0.545-1.713	6	2.695	2.522	1.864-3.412
37	NC	84	324	6	27	66	291	135	107-174	67	0.529	0.375	0.317-0.444	67	1.488	1.086	0.923-1.277
38	MA	79	110	10	21	9	78	39	19-81	8	0.448	0.324	0.190-0.555	9	1.391	1.194	0.845-1.681
39	DC	78	27	15	34	47	54	38	31-47	44	0.388	0.326	0.281-0.379	43	1.895	1.643	1.435-1.881

Table E-10. TSS, total phosphorus, and TKN in mixed runoff (nationwide) from EPA 1983.

Site	State	% Res.	Area (A)	Pop #/A	% Imp.	# Obs	TSS			Total Phos.			TKN			
							Mean	Median	90% Limits	Obs	Mean	Median	90% Limits	# Obs	Mean	Median
1	KS	36	3	68	16	280	208	148-292	7	0.555	0.526	0.413-0.671	0	6.994	6.140	5.004-7.533
2	MD	17	40	72	20	82	43	28-67	20	0.754	0.436	0.291-0.653	19	—	—	—
3	UK	17	3	58	58	282	199	165-239	35	0.498	0.431	0.370-0.503	35	2.822	2.372	2.006-2.805
4	MI	30	11	68	35	85	52	39-69	35	0.198	0.167	0.141-0.197	35	1.490	1.316	1.142-1.516
5	TN	187	3	43	13	71	48	31-74	13	0.352	0.296	0.221-0.394	13	0.623	0.558	0.443-0.705
6	WI	45	12	81	47	383	302	255-357	47	0.289	0.249	0.218-0.284	16	1.452	1.369	1.180-1.589
7	MA	338	7	23	7	351	154	60-395	5	1.176	0.995	0.573-1.726	5	2.446	2.188	1.394-3.432
8	MA	100	1	33	8	30	14-63	8	0.459	0.206	0.088-0.481	8	0.910	0.615	0.615-1.347	
9	MI	453	5	38	23	158	98	69-139	22	0.458	0.384	0.309-0.477	23	1.641	1.506	1.304-1.740
10	MI	2001	2	21	6	46	43	32-58	6	0.103	0.093	0.063-0.137	6	0.845	0.811	0.642-1.025
11	NY	76	—	5	27	291	134	89-202	32	0.363	0.233	0.176-0.309	21	1.237	0.951	0.724-1.249
12	MA	601	9	12	6	150	48	14-166	6	0.534	0.402	0.216-0.749	6	1.888	1.547	0.920-2.601
13	MI	2871	7	26	6	68	61	42-88	6	0.268	0.243	0.168-0.351	6	1.056	1.031	0.862-1.233
14	MI	164	5	28	23	172	131	101-171	23	0.394	0.347	0.285-0.410	23	1.988	1.802	1.536-2.115
15	MI	1207	2	4	5	80	59	28-124	5	0.134	0.117	0.071-0.193	5	1.116	1.104	0.958-1.273
16	SD	2030	—	—	15	3093	1804	1128-2987	15	1.885	1.163	0.743-1.820	13	4.243	3.802	3.010-4.802
17	CA	1542	12	—	19	283	171	115-255	29	0.418	0.374	0.310-0.451	20	2.220	1.775	1.371-2.298
18	FL	30	—	13	15	87	23	11-48	15	0.196	0.160	0.120-0.214	15	1.388	1.249	1.011-1.542
19	FL	194	—	97	14	33	27	20-37	15	0.229	0.204	0.163-0.255	15	1.107	1.056	0.920-1.212
20	CO	69	9	50	32	492	354	278-451	32	0.894	0.673	0.570-0.795	23	4.196	3.522	2.847-4.356



Shown are the median concentrations for 81 sites categorized by land use.
See Tables E-1 through E-10 for further details of this data set.

Figure E-1. Six pollutants in runoff (nationwide) from EPA, 1983.

APPENDIX F

WATER-QUALITY OBJECTIVES FOR AMBIENT SALT WATERS OF BAYS AND ESTUARIES (CALIFORNIA)

From: Water Resources Control Board. 1991. "California Enclosed Bays and Estuaries Plan: Water-Quality Control Plan for Enclosed Bays and Estuaries of California," Tables 1 and 2.

Table F-1. Objectives for protection of saltwater aquatic life.

Chemical	Units	4-Day Average	Daily Average	1-Hour Average	Instantaneous Maximum
Arsenic	µg/l	36	—	69	—
Cadmium	µg/l	9.3	—	43	—
Chromium	µg/l	50	—	1100	—
Copper	µg/l	—	—	2.1	—
Lead	µg/l	5.6	—	140	—
Nickel	µg/l	8.3	—	—	—
Selenium	µg/l	71	—	75	—
Silver	µg/l	—	—	300	2.3
Zinc	µg/l	86	—	95	—
Dieldrin	ng/l		1.9	—	—
Chlordane	ng/l	—	4.0	—	—
DDT	ng/l	—	1.0	—	—
Endosulfan	ng/l	—	8.7	—	—
Endrin	ng/l	—	2.3	37	—
HCH*-gamma	ng/l	—	160	—	—
Heptachlor	ng/l	—	3.6	—	—
PCBs	ng/l	—	30	—	—
Pentachlorophenol	µg/l	7.9	—	—	—
Toxaphene	ng/l	0.02	—	120	—

*HCH = hexachlorocyclohexane

Table F-2. Objectives for protection of human health.

Chemical	Units	30-Day Average
Noncarcinogens		
1,2-Dichlorobenzene	mg/l	18
1,3-Dichlorobenzene	µg/l	2600
Endosulfan	µg/l	2.0
Endrin	µg/l	0.8
Fluoranthene	µg/l	42
Mercury	ng/l	25
Nickel	mg/l	4.6
Toluene	mg/l	300
Tributyltin	ng/l	5.0
Carcinogens		
Aldrin	pg/l	140
Benzene	µg/l	21
Chlordane	pg/l	81
Chloroform	µg/l	480
DDT (total)	pg/l	600
1,4-dichlorobenzene	µg/l	64
Dichloromethane	µg/l	1600
Dieldrin	pg/l	140
Halomethanes	µg/l	480
Heptachlor	ng/l	0.17
Heptachlor epoxide	ng/l	0.07
Hexachlorobenzene	pg/l	690
Hexachloroheptane		
alpha	ng/l	13
beta	ng/l	46
gamma	ng/l	62
PAHs	ng/l	31
PCBs	pg/l	70
Pentachlorophenol	µg/l	8.2
TCDD equivalents	pg/l	0.014
Toxaphene	pg/l	690
2,4,6-trichlorophenol	µg/l	1.0

PAHs*: Sum of Acenaphthylene; Anthracene; 1,2-benzanthracene; 3,4-benzofluoranthene; Benzo[k]fluoranthene; 1,12-benzoperylene; Benzo[a]pyrene; Chrysene; Dibenzo[ah]anthracene; Fluorene; Indeno[1,2,3-cd]pyrene; Phenanthrene; and Pyrene.

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1. AGENCY USE ONLY (Leave blank)			2. REPORT DATE April 1992			3. REPORT TYPE AND DATES COVERED Final			
4. TITLE AND SUBTITLE RECONNAISSANCE SAMPLING OF STORM WATER RUNOFF POLLUTION AT AN ARID INDUSTRIAL NAVY BASE			5. FUNDING NUMBERS PR: ME65 PE: 0603721N WU: DN288604						
6. AUTHOR(S) L. E. Gadbois									
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Command, Control and Ocean Surveillance Center (NCCOSC), RDT&E Division (NRaD) San Diego, CA 92152-5000			8. PERFORMING ORGANIZATION REPORT NUMBER NRaD TR 1497						
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Facilities Engineering Command 200 Stoval Street Alexandria, VA 22332			10. SPONSORING/MONITORING AGENCY REPORT NUMBER						
11. SUPPLEMENTARY NOTES									
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12a. DISTRIBUTION/AVAILABILITY STATEMENT					12b. DISTRIBUTION CODE				
13. ABSTRACT (Maximum 200 words) A storm water runoff sampling program for a large industrial facility without a centralized storm drain system was developed and tested. The approach allows assessment of environmental impact, source identification, and guidance for management. Contaminant levels were found to be extremely variable, and at times, sufficient to pose an ecological risk. Worst-case first-flush samples following varying intervals without rain are compared with late storm flow samples to assess the full range in contaminant concentrations. Innovative sampling, analytical, and management methods are discussed.									
14. SUBJECT TERMS nonpoint source pollution water pollution monitoring					first flush ecological risk assessment			15. NUMBER OF PAGES 68	
								16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED		18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED		19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED		20. LIMITATION OF ABSTRACT SAME AS REPORT			

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